NOV 7 1924

ECONOMIC GEOLOGY

VOL. XIX. NOVEMBER, 1924. No. 7

# THE GOLD ORES OF GRASS VALLEY, CALIFORNIA.*

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## INTRODUCTION.

SOME thirty years ago the gold quartz veins of the Grass Valley district in Nevada County, California, were studied by Lindgren and his reports[1] have ever since guided and inspired those who were engaged in geologic work in the mines. An increasing knowledge of the character of the ore deposits, due to the extension of underground work, has suggested modification of Lindgren's theories regarding their origin. Evidence is presented in the following pages that leads to the conclusion that the quartz veins were formed by replacement. It is further shown that the introduction of gold followed a fracturing of the quartz due to slight movements on the vein fissures and that the occurrence of ore in shoots is to be attributed largely to this mechanical cause.

## AREAL GEOLOGY.

The geology of the district is so well known that it is only necessary to present a brief outline of its more important features. Grass Valley lies on the slopes of the Sierra Nevada to the west of the great batholith that makes up the core of the

* Presented to Society of Economic Geologists, New York Meeting, May, 1924.

[1] Lindgren, W., "The Gold-quartz Veins of Nevada City and Grass Valley Districts, California," 17th Ann. Rep. U. S. Geol. Survey, pt. II., pp. 1–262, 1896. "Nevada City Special Folio," No. 29, Geologic Atlas of the U. S., U. S. Geol. Survey, 1896.

Cordillera. Outlying masses of the granitic rocks occur at many places in the foothills, intruding rocks of Paleozoic and Mesozoic age partly of sedimentary origin and in part igneous. At Grass Valley the upper portion of a small batholith, or outlier of the main mass of the Sierra Nevada intrusives, is exposed and is seen to intrude sediments of the Caliveras formation and a complex of rather basic igneous rocks described by Lindgren as porphyrite and diabase. It is an elongate body, its greater diameter having a trend slightly west of north; its greatest width is a little under two miles and its length is nearly five miles.

Mine workings have shown that the exposed portion of the batholith must be near the top of a dome-shaped mass and that the rocks which it intruded once formed a continuous arch above it. The rock of which the batholith is composed was described by Lindgren as a granodiorite; today it would probably be called a quartz-monzonite but the term granodiorite has come to be so well known in the district that it will be used in this description. A few dikes occur in both granodiorite and porphyrites. Some are rather basic and perhaps best described as quartz-diabase. Others are acid and are essentially fine grained granite-porphyries or aplites, usually known in the district as quartz-porphyries. A superjacent series of rocks, with which the present study is not concerned, consisting of fragmental material of volcanic origin, remains as a capping of some of the higher hills and is of Tertiary age.

## STRUCTURE.

The surface geology is obscured by a thick mantle of soil and vegetation so that knowledge of the structural features is gained largely from observations underground in the mines. The structure is admirably described by Lindgren and the principal fissure systems are accurately shown on the geologic maps. The most pronounced system of vein fissures has a northerly trend. To the southeast of Grass Valley, these are best represented by the Empire group of veins which strike north and dip to the west at angles of from twenty-five degrees to thirty degrees. To the westward is another group, less well defined, of north-south veins

which dip to the eastward. Another system, to which the North Star belongs, has a nearly east-west trend, the principal members of the system dipping to the northward at angles of from twenty-five degrees to thirty degrees. A corresponding system with southerly dips also occurs but is not prominent.

The principal veins lie either in the granodiorite or porphyrite-diabase and consequently it is practically impossible to discover the extent of faulting that has taken place on the various fissures. It is known that the differential movement of the fissure walls has been of a reverse nature and it is believed that, in most instances, the displacement has been slight. It is helpful in drawing a picture of the broad structural features, to regard the central portion of the district, extending from the town of Grass Valley southward along the axis of the granodiorite and in the direction of Wolf Creek, as a wedge bounded east and west by fault planes, the lower sides of which have moved downward with respect to the wedge. To a less marked degree, the same relationship holds with respect to the east-west system of fissures.

In addition to the vein fissures, there is a system of distinctive barren fissures that are nearly vertical and have a northeasterly strike. They may appear either as single distinct fissures without vein filling, or as zones of sheeting. Nearly all of the veins are cut by these vertical fissures which are locally known as "crossings," but in only a few instances have they faulted the veins and then to an extent measured in inches rather than in feet.

## VEINS.

The gold-quartz veins of the district occupy the fissures of the different systems that have been described, the "crossing" fissures being conspicuous exceptions. The veins consist of quartz and a little calcite with variable amounts of sulphides of which pyrite is the most abundant. Chalcopyrite and sphalerite are present in moderate amounts and there is usually a little galena closely associated with the gold in the richer ore.

The ore occurs in shoots, the longer axes of which pitch in the

general direction of the dip of the veins. Lindgren points out [2] the generally observed fact that the ore shoots appear to pitch to the left as one stands at the outcrop and looks down the dip of the vein. This, in general, holds true in the case of all of the principal veins of the district. From the point of view of the mine operator, an understanding of the causes that have combined to bring about the concentration of pay ore in definite shoots, is extremely important. A knowledge of the origin of the veins, as a whole, is essential in studying the problem of the ore shoots, and it is with this subject that the present paper deals.

Lindgren's theories regarding the origin of the gold-quartz veins have been generally accepted until recent years but today there is a tendency to question some of the early conclusions. Lindgren considers that the veins were formed in preëxisting cavities through the agency of "thermal waters, containing carbonates, silica, and sulphureted hydrogen or sodium sulphide, and containing also measurable quantities of gold and metallic sulphides." [3] Petrographic and chemical studies of the altered wall rocks indicate that metasomatic changes were brought about through the agency of mineralized thermal waters of this character. It has become evident to those who more recently have been studying the deposits that the veins can not satisfactorily be accounted for by the filling of open spaces through the agency of dilute solutions. Some of the evidence that conflicts with the early theory is presented in the following paragraphs.

*Description of Veins.*—The characteristic features of the quartz veins that lie just south of the town of Grass Valley have been well described by Lindgren.[4] Some, however, show individual peculiarities. The typical vein filling consists of more or less crushed and altered country rock and quartz, and is from a few inches to eight or ten feet in width. Variations appear in all of the veins that have been studied; some show evidences of greater differential movement on the part of the fissure walls and

[2] *Op. cit.*, p. 160.
[3] *Op. cit.*, p. 182.
[4] *Op. cit.*, pp. 112–131, 158–171.

consequently there is more crushed rock within the fissure. The quartz may vary from a fraction of an inch in tight, barren veins to thicknesses of from four or five feet. It may be in contact with one or another of the fissure walls, but is usually developed near the center of the fissure and separated from the walls by fractured country rock. Instances where the quartz is in sharp contact with both hanging and footwalls are rare and usually are found in barren portions of the veins and where the quartz is of no great thickness. Within the quartz itself, it is the rule to find angular or subangular fragments of country rock which may make up from one to twenty-five per cent. of the volume of vein between the walls. These fragments are usually altered in the same way and to the same degree as the enclosing wallrocks and, like the wallrock in the neighborhood, frequently are found to contain small cubes of secondary pyrite. This pyrite is distinct from that which occurs in the quartz itself and with which the gold is associated.

It is evident that later movements in many cases have occurred along the fissures. For example, the quartz is frequently separated from the wall rock by a narrow band of sheared country rock, or by a film of gouge, or the quartz itself may be sheared, resulting in a banding or ribbon-like structure near the walls, a common feature described by Lindgren,[5] and marked by crushed and drawn out rock fragments and patches of pyrite. Some of these features are shown in Plate X., *B*.

Considerable calcite is often present, either crystalline and essentially contemporaneous with the quartz, or as later films that ramify the quartz and adjacent country. There may be two or more quartz veins between the fissure walls; one may be near the hanging wall and another developed close to the footwall with crushed and altered country rock between them. A single quartz vein may split into several smaller ones, connected by stringers which farther on combine to form a single vein. Veinlets of quartz commonly traverse the fractured country rock between the fissure walls as shown in Plate X., *B*.

[5] *Op. cit.*, p. 129.

The description just given applies to most of the quartz veins of the Grass Valley district, but some exceptions have been found which deserve special description. For example, the vein may be made up of coarsely crystalline, sometimes glassy, quartz in crystals one inch or more in length, often radiating from greatly altered inclusions of country rock, or attached to an undulating surface of more compact quartz which has developed on the foot-wall. Between the quartz crystals is finely crystalline calcite, the calcite making up perhaps thirty per cent. of the vein matter.

*Ore Shoots.*—The ore occurs usually in well defined shoots whose longer axes follow closely the dip of the veins. The shoots may be from fifty to two hundred feet in breadth and one thousand to fifteen hundred feet in length. They are to be distinguished from the barren portions of the veins not only by their higher gold content, but also by a greater width and by the fact that the quartz is in stronger and thicker bands that contain more abundant sulphides. The ore shoots appear, in many instances, to have been determined by the intersection of two fissures which may be regarded as belonging to the same system but which show a difference in strike of ten or fifteen degrees. The ore shoots follow the line of intersection and their pitch is determined by the dips of the intersecting fissures. Frequently, the ore shoot does not develop at the actual intersection but lies near by on one of the fissures. Shoots also are found in parts of a vein where no intersection is visible.

One other structural feature well recognized by the miners of the district appears to have had a decided influence on the occurrence of ore. For example, where the "crossings," previously noted as being barren vertical fissures and usually extremely wet, intersect a vein, a marked change for better or worse in the character of a vein almost invariably occurs.

*Ore.*—Ore, as distinguished from barren or low-grade quartz, is characterized by the presence of bunches and streaks of sulphides. In ore of good grade, the sulphides may make up four per cent. of the vein; the amount is frequently less and large masses of sulphides are extremely rare in the Grass Valley dis-

trict. Of the sulphides, pyrite is most abundant, moderate amounts of blende are usually present, occasional small quantities of chalcopyrite are found and galena, in subordinate quantities, is invariably an indication of rich ore. Gold is rarely visible to the eye, even in good ore, but occasional spectacular specimens are found in which the gold is commonly associated with the sulphides, although occasionally it occurs in quartz alone.

### ORIGIN OF ORE SHOOTS.

It has been impressed on everyone who has studied the ore deposits of the Grass Valley district that the occurrence of ore shoots must be dependent on certain definite causes but just what these causes were has always been obscure. From my own observations, I have felt that a number of different factors must enter into the problem. Mechanical causes seem to be indicated by a very general relationship of ore shoots to vein intersection, a feature characteristic of fissure veins in many parts of the world. The usual explanation offered is that ore has developed as the result of the mingling of solutions of different chemical composition derived from the intersecting veins. No convincing evidence has been offered in support of this possibility. Studies of many veins have failed to show any differences in the composition of the vein fillings which would indicate ore-bearing solutions of sufficiently diverse character to have brought about concentration of the ore minerals in places where the supposedly different solutions might have mingled. The possible influence of wall rocks on the occurrence of ore is another factor that has been considered. A careful petrographical study of both granodiorite and diabase-porphyrite, at and near ore shoots and at barren parts of the vein, has merely confirmed the work of Lindgren as regards the character of the metasomatic processes which have affected the wall rocks. It is true that the presence of calcite as a secondary mineral in the wall rocks is variable. In the granodiorite of the North Star vein, especially in the lower portion of the mine, calcite is not particularly abundant. It is far more common as a secondary mineral in the altered porphyrites and

diabases, nearer the surface. The gold content of quartz has always been regarded as higher where the vein lay in diabase than in granodiorite. In studying another vein of the North Star system, which lies partly in diabase-porphyrite but for the most part in granodiorite, it was found that practically all of the good ore lay between walls of granodiorite and that calcite was more abundant as an alteration product in the wall rocks of granodiorite than in the diabase-porphyrite. The evidence, therefore, is conflicting and it is believed that although the wall rock may have had some slight chemical influence on the development of ore, other and more pronounced factors have been the controlling ones. The negative results of these studies led to the conclusion that the only way to attack the problem was to start at the beginning with an open mind and subject all the available evidence to the most rigid scrutiny. As a result of recent studies, the following outline of the origin of the Grass Valley ores is presented.

*Fissures.*—The fissures of the district have already been described but more may be added regarding their origin. According to Lindgren,[6] the fissures developed as a result of compressive stresses "applied in different directions, chiefly from east to west and from north to south," causing thrust faults of moderate throw with fracturing and, in extreme cases, crushing of the country rock. It is believed that these stresses developed locally at the close of the period of granodiorite intrusion. It has been observed frequently that fractures occur in the upper portions of a batholithic intrusion and in the overlying rocks which have every appearance of having been brought about by tension due to the expansive force of the intrusion still in progress. When this force was spent and the consolidation of the granodiorite was in progress, a settling of the lower portions of the intrusive is believed to have taken place. With the withdrawal of pressure from below, the arched roof of the new batholith would be compelled to support the weight of the overlying rocks and the tension fissures would be closed. As a further result of the shrinkage or sagging, lateral pressure on the flanks would tend

[6] *Op. cit.*, p. 170.

to force inward the invaded rocks and the outer portion of the batholith, producing strains that would find relief in reverse faults of moderate throw and of lower angles of dip than the tension fissures first formed. The result of such movements, which were probably extremely slight, would be systems of fissures such as are found in the Grass Valley district, dipping toward a central point. Evidence in favor of such an explanation is found in the relation of the pronounced north-south fissures to the general northerly trend of the elongate exposure of the granodiorite batholith, with the less pronounced east-west systems of fissures transverse to the longer axis of the batholith. Everywhere, the fissure walls indicate that their differential movement was of essentially a reverse nature. Furthermore, the space between the walls is occupied by more or less crushed country rock, indicative of pressure rather than tension. It is further believed that the earlier formed fissures of the tension type were, during the period in which the vein fissures were developed, closed and compressed and that slight differential movements of their walls may have taken place. The "crossings," to which reference has already been made, are regarded as belonging to this system of closed tension fissures. It has been observed in many places that crossings may fault the vein fissures but it is also true that the crossings are quite as often faulted by the veins. For the most part, veins and crossings intersect without noticeable displacement of either fissure. Where displacement has occurred, it is of very minor extent, and at the most, may be but three or four feet. It will be noted that the crossings are older than the vein fissures but a little faulting has, in some instances, occurred which corresponds in time to that in which the vein fissures developed. Consequently, insofar as the origin of the ore is concerned, the crossings and vein fissures may be regarded as essentially contemporaneous.

Immediately after the formation of the fissures, the vein matter was introduced, consisting of a gangue of quartz with a little calcite and pyrite. The manner in which the quartz and metallic minerals were introduced into the fissures will be con-

sidered later. For the present, it is sufficient to state that all of the main quartz veins were developed at the same time and that their characteristic features were practically the same as they are today. It is apparent, however, from evidence obtained from many widely separated points that, following the introduction of quartz, readjustments continued along previously determined lines of weakness, the slight movements resulting in slip planes and zones of minor crushing, both in the rock within the fissure walls and in the quartz veins themselves. Certain portions of the veins show these readjustments to a marked degree; at other places, little or no evidence of movement subsequent to the introduction of the main quartz veins may be observed.

*Enrichment of the Veins.*—Following the period of fracturing of the quartz veins, there appears to have been a second period of mineralization characterized by quartz, calcite, sphalerite, galena and gold. A microscopical study of the ores shows that the pyrite of the first period of vein formation has been fractured or crushed as a result of the later movements on the vein fissures and that the quartz is traversed by fine cracks which may, in extreme cases, develop into long-drawn-out lines of crushed quartz grains. In some cases, the fractured quartz has been re-cemented by later quartz. In other cases, the cementing material has been calcite. The pyrite may have suffered only slight fracturing as the result of the later movements, or it may have been very completely crushed. Frequently, the edges of pyrite masses or large grains are granulated while the interiors are traversed by innumerable fractures. The crushed pyrite and the cracks in the more massive material are re-cemented and replaced by later quartz, gold and galena. The gold penetrates the finest cracks in the pyrite. Quartz is probably next in its degree of penetration while galena takes third place. This association of gold with the pyrite points clearly to the pyrite as the precipitant of the gold and galena. Less commonly gold occurs in the fractured quartz, not in contact with pyrite. Where gold is found in such relationship, however, there are usually masses of pyrite in the immediate vicinity. This description applies to perhaps

eighty per cent. of the ore specimens examined. In the remaining twenty per cent., where gold is seen to occur with pyrite, it is not possible to assert definitely that the gold is the younger. It appears as small specks or blebs within what seems to be massive and unfractured pyrite. Such occurrences are rare and the amount of gold is in no way comparable to that which is seen to be clearly younger than the pyrite. It is quite possible that this gold may be of the same age as the pyrite which, in turn, belongs to the first period of vein formation. It is also possible that appearances are deceptive and that what is taken for original gold may indeed be the ends of veinlets following fractures in the pyrite which are not shown in the section. With respect to the eighty per cent. of the gold which replaces and fills cracks in the pyrite, together with quartz and galena, there can be no question whatever regarding its later origin.

It is interesting to note in this connection that in those portions of the veins that carry only low-grade or barren quartz, little or no evidence has been found that the quartz has been fractured by later movements that have left their mark so conspicuously on the richer portions of the veins. Furthermore, the barren veins carry quartz only two or three inches in thickness at the most and seldom show more than a trace of sulphides. With these facts in mind, we may now turn to a consideration of the occurrence of ore in well-defined shoots.

*Ore Shoots.*—As has been said, in a large number of cases, the shoots lie at or near the intersection of two vein fissures. Furthermore, they are characterized by quartz from six to twenty-four inches in thickness. This variation in thickness of the quartz veins is not difficult to account for when one remembers that the so-called planes along which the original fissuring took place are not planes in any sense of the word but rather undulating surfaces which vary in dip and also in strike. Any movement that may have taken place on these fractures must have resulted in the shifting of the respective walls in such a way that alternating swells and pinches were developed in the fissures. It has been customary in the past to account in this way for the

necessary open spaces later occupied by mineral veins. Whether actual open spaces existed need not for the moment be considered. The fact, at least, remains that at certain portions of the fissures the wall rocks were practically in contact and offered little opportunity for the introduction of the gangue and ore minerals. At other places, the walls of the fissures were farther apart and the space between presumably filled with fractured or crushed country rock which offered more favorable channels for the introduction of the ore-forming materials. It is reasonable to suppose that such favorable loci for the development of veins would be found at and near intersecting fissures, but they may also occur in other portions of the veins where differential movement resulted in the separation of the fissure walls to a greater extent than at other parts of the fissures. With these suggestions in mind, the curious influence of crossings or barren vertical fissures on the occurrence of ore shoots becomes less obscure. It is conceivable that in the first period of readjustment in which the vein fissures were formed, fractures developed which passed through the preëxisting crossings. Differential movement of the walls of these fractures would be influenced by the crossings in such a way that moderate displacement might take place on one side of the crossing and a more pronounced movement of the hanging wall with respect to the footwall would take place on the fissure on the other side of the crossing. In this way, a possible locus for the coming quartz would be developed on one side of a crossing in the vein fissure, whereas movement might be reduced to a minimum on the other side, leaving no available spaces, actual or potential, to be occupied by quartz.

Coming next to the period of enrichment of the earlier quartz, following later movements which fractured the vein and provided channels for the enriching materials, one finds again that the neighborhood of intersections is favorable for the development of these later fractures. It is conceivable that such movements may have occurred at any place on a vein fissure, but at intersections there are obviously two chances that such movements may have occurred and have brought about a fracturing of

the quartz veins. In the same way, veins in the neighborhood of crossings are more likely to have suffered fracturing than at a distance from such lines of weakness. It is believed, therefore, that the ore shoots have formed as the result, first of all, of structural features such as the intersection of veins. Subsequently, fracturing of the earlier introduced quartz permitted the circulation of gold-bearing solutions. This explanation seems to fit the observed facts in every way and accounts for many puzzling features of the gold quartz veins that, up to now, have been difficult to understand. One link in the chain of evidence, however, is somewhat weak and that is the manner in which the original quartz was introduced. Although this does not directly affect the conclusion reached regarding the origin of the ore shoots, nevertheless it deserves special consideration and in many ways is the most interesting problem connected with the study of the Grass Valley ore deposits.

### ORIGIN OF THE QUARTZ.

In the course of investigations carried on, especially at the North Star Mines, evidence has been accumulating in the last few years which has led to doubts regarding the soundness of Lindgren's conclusions as to the manner in which the gold-quartz veins were formed. According to the hydrothermal theory, the origin of the gold-quartz veins of the Grass Valley district was intimately connected with the granodiorite batholith. It is assumed that magmatic waters escaped from the cooling magma and found their way into the overlying rocks and that ultimately they reached the surface as hot springs through channels determined by preëxisting fault fissures. It is further assumed that these waters contained in solution substances which were slowly deposited on the walls of the fissures through which the waters flowed until the open spaces were completely closed by quartz, calcite and metallic sulphides. As further evidence that heated waters charged with mineral were intimately associated with the origin of the quartz veins, it is pointed out that the wall rocks adjoining the vein fissures have undergone alteration through the

replacement of their original minerals by substances carried upward in solution. The nature of this alteration suggests that the solutions which brought it about were those of alkaline carbonates and sulphides. Chemical analyses of altered wall rock presented by Lindgren [7] show that certain constituents, notably silica, soda, magnesia, and iron, were removed and potash, calcium, and carbon dioxide were added. With that portion of Lindgren's hypothesis which connects the ore deposits with the granodiorite magma, there can be no differing opinion. Concerning the manner in which the quartz and its associated gangue and ore minerals were transported and deposited in their present positions, more needs to be said.

*Fissure-filling.*—The preëxistence of continuous open spaces which served as channels for rising thermal waters and on the walls of which the ore-bearing solutions were supposed to have deposited the vein minerals is today seriously doubted, although the occasional occurrence of cavities of small size is recognized. At the depths at which ore deposition is believed to have taken place, it is difficult to account for open cavities of a magnitude sufficient to have served not only as channels for circulating waters but to have permitted the development of quartz veins of several feet in thickness. It has been held by some that the ore-bearing solutions were under sufficient pressure to hold the walls of fissures apart while the process of ore deposition was going on. Whether this is physically possible, a careful study of the vein fissures of the Grass Valley district leads one to believe that some agency other than that of relatively dilute solutions must be sought to account for the observed facts.

A typical section of one of the quartz veins shows that the hanging and footwalls of the fissures are from eight to ten feet apart. The hanging wall is well defined and its surface is marked by slickensides. Above the hanging wall the country rock is usually altered but, except for joint planes, shows little or no evidence of crushing or shearing. Below the hanging wall there may be two or three feet of fractured rock, traversed by veinlets

[7] *Op. cit.*, pp. 149–157.

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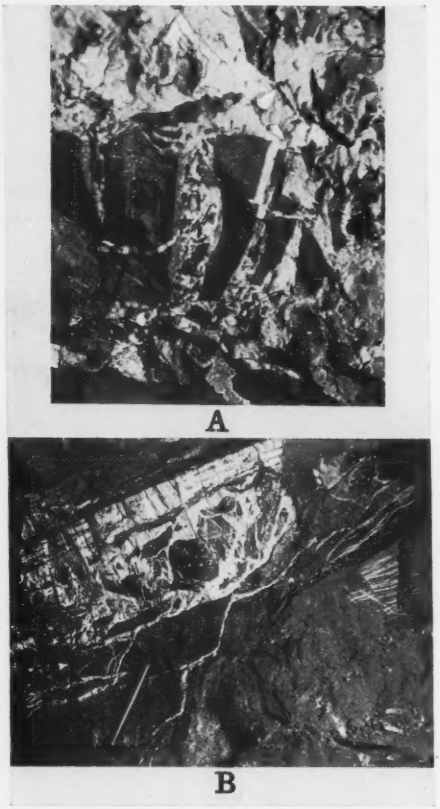
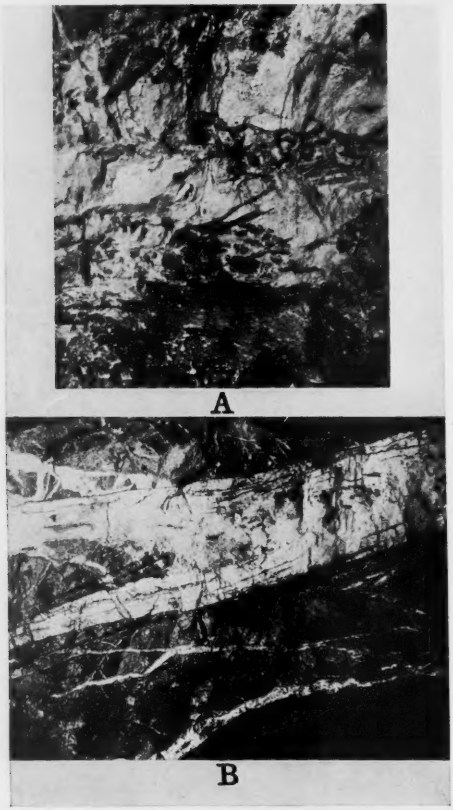


A

B

*A*. Ill-defined contact between quartz and wallrock, due to partial replacement of diabase and its preservation as angular residuals in quartz. Exposure four feet in length. New York Hill vein, North Star Mine.

*B*. Quartz vein, nineteen inches wide, with inclusions of granodiorite. Narrow bands of partly replaced rock are shown as inclusions near the upper surface of the quartz. Six inches of crushed rock lies between the upper surface of the quartz and hanging-wall of the vein fissure. Below the quartz the country rock is traversed by veinlets of quartz and calcite. New York Hill vein, North Star Mine.




*A*. Irregular footwall contact of quartz vein with granodiorite. Just below the center is an aggregate of rock fragments included in quartz, that appear to have been once parts of a larger mass, the curved outline of which is partly preserved. North Star Vein.

*B*. Wedge of granodiorite partly replaced by quartz. The thick end of wedge is of nearly fresh rock. The tip of the wedge, (indistinctly shown to the right of the center), has been almost completely replaced. North Star Vein.

of quartz or calcite, and altered in the same way but usually to a somewhat greater degree than the country rock. Next is a band of quartz, some eight or ten inches in thickness, whose upper surface is separated from the crushed rock within the fissure by a layer of soft material that may be recognized as thoroughly mashed country rock or which may have been so completely crushed as to be described as gouge. With the undersurface of this layer the quartz is in sharp contact (Plate X., *B*). Below the quartz is another band of rock three or four feet in thickness, more crushed and sheared than the upper layer, and carrying numerous well-defined veinlets of quartz and calcite which connect the first quartz band with a second of the same general character. This lower band of quartz is separated from the footwall country rock by a thin layer of gouge. Closer study shows that the footwall quartz carries numerous inclusions of country rock which have been altered in the same way and in the same degree as the country rock lying between the fissure walls. The first quartz band in the middle of the fissure may also carry inclusions of country rock or may be marked by thin dark seams which lie within the quartz parallel to its upper surface.

Other veins, or the same vein at different places, may show different features. The fissure walls may be nearly in contact with one another, the space between filled with a little crushed country rock and a vein of quartz one inch or less in thickness. In another vein, the fissure walls may be the same distance apart as those of the type described but only one quartz band may be present, in which case it may have a thickness of two or three feet. Everywhere, however, the quartz veins contain large and small inclusions of rock and the vein itself is in sharp contact with the country rock, whether at a true hanging or footwall or lying within the vein fissure and separated from the walls by crushed country. Stringers of quartz or calcite frequently leave the main vein and penetrate the fractured rock within the fissure for distances of many feet. These also may carry small angular inclusions and are invariably in sharp contact with the country rock (Plate X., *B*). Rarely, a gradation of quartz into country.

rock is observed. The gradation, however, is a purely mechanical one, rock at a distance from a prominent quartz vein being traversed by numerous stringers or veinlets; as the main body of quartz is approached, these stringers become larger and the quantity of wall rock lying between the stringers less, until, within the quartz itself, the wall rock is merely represented by inclusions, many of which are angular (Plate X., *A*).

It is difficult to see how these different features which are characteristic of all the quartz veins could have been brought about as a result of the deposition of quartz in open spaces from dilute solutions, the presence of unsupported fragments of wall rock in the quartz alone being sufficient to justify the rejection of the hypothesis. It becomes necessary, therefore, to suggest some other way to account for the presence of the quartz.

*Force of Crystallization.*—The force of growing crystals has been considered by some [8] to be sufficient to separate the walls of a fissure and permit the growth of mineral veins which, when completed, would have all of the characteristics of those at Grass Valley. Such a theory might account for the presence of fragments of wall rock included in the interior of the quartz veins, since large and small masses of rock might be split off by veinlets penetrating the wall rock from the growing quartz and, as growth continued, might in time find themselves farther and farther away from the vein walls. Although the force of growing crystals may be perhaps sufficient to account for the opening of the fissures, nevertheless veins built up in such a manner would presumably show a definite structure with a more or less parallel development of greatly elongated quartz crystals, normal to the vein walls. Such a vein might consist of fibrous quartz or coarsely crystalline quartz but it is difficult to understand how the characteristically granular vein quartz interlocking and showing little evidence of strain could have formed had the space which it now occupies resulted from the force of the growing crystals.

[8] Taber, Stephen, "Mechanics of Vein Formation," *Trans. A. I. M. E.*, LXI., pp. 34–36, 1919; "Origin of the Bendigo Quartz Veins," ECON. GEOL., vol. XIII., pp. 538–546, 1918. Stillwell, F. L., "Vein Filling at Bendigo, Victoria," ECON. GEOL., vol. XVI., pp. 153–159, 1921; "A Bendigo Problem and Its Bearing on Force of Crystallization," ECON. GEOL., vol. XVIII., pp. 506–510, 1923.

*Igneous Intrusion.*—There is a belief on the part of some geologists that certain types of mineral veins have been formed by processes comparable to those which have long been recognized as responsible for the occurrence of igneous dikes. Recently processes of vein formation of this kind have been described by Spurr.[9] Following the intrusion of masses of quartz-monzonite or granodiorite such as that forming the core of the Sierra Nevada, the chilled and fissured portions of the batholiths and overlying rocks are invaded by dikes, some of which are more basic than the rock composing the batholiths and others are more acid. It is assumed that the magma of which these dikes are composed was derived by differentiation from the crystallizing magma of intermediate composition making up the batholith. The youngest of these dikes are of the kind known as pegmatites. They belong to the acid end of the series, are coarsely crystalline and, before their consolidation, contained water in notable quantities. In addition to quartz, feldspars and mica, pegmatite dikes frequently contain traces of metallic minerals. It is further believed by the proponents of the theory of the igneous origin of mineral veins that a continuing differentiation of the parent magma may result in the development of a still more siliceous product, less rich in water than the pegmatites, which, when intruded into the overlying rocks, crystallizes in the form of quartz veins carrying other gangue and ore minerals. Such intrusions for which the name "veindikes" has been proposed by Spurr[10] are believed to follow closely after the intrusion of complementary dikes and pegmatites. In reality this theory differs but little from a number of earlier ones which have closely linked the origin of mineral veins with the occurrence of igneous rocks. It differs essentially in the assumption that the mineral veins represent actual differentiates of an igneous magma rather than that they were precipitated from mineral-bearing waters given off by the crystallizing parent magma. The distinction is perhaps a fine one. The real difference lies in the fact that veindikes are as-

[9] Spurr, J. E., "The Ore Magmas," McGraw-Hill Co., New York, 1923.
[10] *Op. cit.*, p. 70.

sumed, at the time of intrusion, to have had a body or substance greater than that of heated waters carrying in solution relatively small quantities of mineral matter.

The theory of the intrusive igneous origin of mineral veins assumes that the vein materials were injected under conditions of pressure sufficiently high to force apart the walls of the fissures and make room for the veins in the same way that dikes invade overlying rocks. It is also assumed that the veindike magma is of sufficient substance to support fragments of wall rock which may find their way into the magma during intrusion and hold such fragments in suspension until the veins have solidified, or that the veindike congealed quickly, thus preventing the sinking of suspended rock fragments. Certain features that characterize the Grass Valley ore deposits might be accounted for by the theory that the veins were introduced as igneous intrusions. One such is the presence of more or less angular inclusions of wall rock in the quartz. Similar inclusions are common near the contacts of many dikes where there can be no doubt that these were torn from the country rock at the time of intrusion and supported by the cooling magma until its consolidation.

A characteristic of the quartz that is difficult to explain by the hydrothermal hypothesis and that may be construed as evidence in favor of the intrusive origin of the quartz is that the quartz veins are usually separated from the hanging walls of the fissures by several feet of crushed country rock, a condition that could hardly exist were the vein assumed to have filled an open space below this same crushed country by slow precipitation of ore-bearing solutions. If it is assumed that the quartz was intruded as an igneous rock, this relationship is easily explained. As an intrusive, the invading magma would follow lines of least resistance, forcing apart the wall rocks where they were close together or pushing aside the crushed country in portions of the fissures where the walls were far apart, picking up and supporting fragments of the fractured country rock as intrusion continued. The sharp contacts of the quartz with the country rock, whether the rock be nearly fresh or reduced to the extreme of

alteration, apparently is easily accounted for if the veins are regarded as intrusions.

Attractive as this theory is, which would account for the quartz veins as igneous intrusions, there are yet a number of objections to its complete acceptance for the Grass Valley veins. The presence of angular inclusions of wall rock in quartz veins may, at first glance, readily be explained by the theory that the veins are in reality intrusive rocks. The conception of the veins as intrusives implies comparatively rapid movement on the part of the invading magma. If this be true, the included fragments of wall rock in considerable numbers would be swept beyond those parts of the vein walls from which they were detached. This is a point difficult to prove or disprove but where the North Star vein passes from between walls of granodiorite into the overlying diabase-porphyrite it has been found that fragments of granodiorite included in the quartz end abruptly and that above the contact only diabase-porphyrite inclusions occur. It has been noted, moreover, in numerous cases that rock fragments within the quartz show the same degree of alteration as the adjacent wall rocks, a feature difficult to explain were the fragments regarded as having been torn from the wall rock, carried onward by the advancing magma and, on its consolidation, permanently sealed within the solid quartz. If the alteration of the wall rocks is assumed to have taken place after the quartz intrusion, it is difficult to explain the fact that large and small inclusions of rock have been altered in the same way and to the same degree as the adjoining wall rocks. Although inclusions of wall rock are, in most instances, distinctly angular, yet there are notable exceptions to be found almost everywhere that inclusions occur. In some cases, the inclusions are clearly not angular but rounded. In other cases, groups of inclusions are so arranged as to suggest that they are parts of a once solid larger fragment and that if they were removed from the quartz matrix, they might be joined together so as to reconstruct the original larger rock fragment. Examples of this type are shown in Plates X. and XI., *A*. As a matter of fact, such groups of fragments could not be fitted to-

gether in the simple way suggested, since adjacent surfaces would seldom make a perfect match. It is also hard to believe that the individual fragments could be separated by uniform thicknesses of quartz and, in their arrangement, still indicate the original form of the larger block, if the invading magma were flowing even slowly. The same objection applies to a not uncommon case where trains of fragments lie in such a way that their upper surfaces are nearly in line and parallel to the upper contact of the vein with the wall rock and separated from it by an inch or more of quartz. A veindike is supposed to make room for itself by forcing aside the walls of the fissure it is invading. That some such process is possible is indicated by dikes that have been observed in all regions of igneous rocks. When, however, a vein is found lying in the midst of crushed rock separated by several feet from the fissure walls, it would be natural to suppose that the force of intrusion would have left some record that could be recognized in the relatively soft, crushed rock lying between the fissure walls. Such evidence has not been observed. It must be admitted that there are parts of many veins that present evidence that appears to prove conclusively their origin as veindikes. Yet other parts of the same veins present such serious objections that it seems impossible to accept this theory as one that satisfactorily accounts for all of the observed facts.

*Replacement.*—All of the evidence that can be gathered in the field and laboratory points to the fact that dilute thermal solutions of the alkalies, carbon dioxide, sulphur, and silicon, given off by crystallizing granodiorite magma, penetrated the overlying rocks following previously formed fissures as main channels. This evidence has been clearly presented by Lindgren[11] but it deserves to be reviewed briefly because it is, by all means, the most definite clue available as to the origin of the gold-quartz veins.

It is a fact of common observation that the wall rocks, whether granodiorite or diabase, have suffered characteristic and often extensive alteration in the vicinity of the veins. The rock is bleached, softened, and, in extreme cases, has completely lost its

[11] *Op. cit.*, p. 172, et seq.

identity. The microscope shows the alteration to be of the type resulting from the action of hydrothermal solutions of alkalies, carbon dioxide, and sulphur on crystalline igneous rocks. Feldspars and ferromagnesian minerals have been replaced by sericite, calcite, and chlorite, pyrite is often present as a secondary mineral and epidote is not uncommon. The action has been most intense in the crushed country rock that is usually present between the fissure walls. The intensity decreases at a fairly uniform rate as distance from the fissures increases. Furthermore, there seems to be a definite relation between the extent and intensity of the alteration of the wall rock and the size of the vein. Near tight, barren veins, the country rock is comparatively fresh but where the fissure is a large one and the quartz abundant, the alteration is most intense and extends to greater distances from the fissure. One can not escape the conclusion that there must have been an intimate connection between the processes that brought about the alteration of the country rock and that by which the quartz veins themselves were formed. Metasomatic quartz has not been recognized as one of the minerals replacing the granodiorite or diabase; calcite, however, is universally present in the altered country rock and is frequently found associated with the vein quartz in such a way as to indicate that quartz and calcite formed contemporaneously. In this connection, it is well to note that, where introduced calcite is referred to, in many cases the mineral contains sufficient iron to give it a distinct rusty appearance on exposed surfaces; it is doubtful, however, if pure iron carbonate has developed. So far as my own observations go, quartz and calcite are the only gangue minerals present in the Grass Valley veins. Microscopical studies of the vein matter and wall rocks have confirmed field observations and are in complete agreement with those of Lindgren.

As shown in this paper, the facts of observation do not seem to lend strength to the belief that the quartz veins were formed by the precipitation from dilute solutions of the vein-forming minerals in open spaces, while there are a number of serious objections to the theory that the veins were injected as dikes. It

remains, therefore, to consider the quartz veins as having been formed through direct replacement of the country rock by solutions which at the same time brought about the marked metasomatic changes of the wall rocks.

If replacement be accepted as a working hypothesis, it is necessary to inquire regarding evidence in support of the theory as well as that which may be in conflict with it.

Reference has already been made, in discussing the veindike hypothesis, to remnants of country rock in the form of thin bands parallel to the vein walls and lying an inch or more within the quartz. These are well shown in the upper part of the quartz in Plate X., *B*. In the same vein, one may find all gradations from the thin bands of included country rock such as have just been described to trains of angular rock inclusions that show the same striking parallel arrangement with respect to the vein wall. The impossibility of accounting for such occurrences either by the hypothesis that open spaces were filled by slowly precipitating quartz or that the quartz was introduced as a veindike has already been discussed. On the other hand, the sharply angular inclusions shown in the lower portion of the quartz in the same plate are hard to reconcile with the replacement hypothesis. As Lindgren has pointed out,[12] the fissures in which the veins now lie were probably in most cases compound ones, the entire space between the main hanging and footwalls being filled with crushed country rock traversed by "walls" that often resemble the main fissure walls so closely that they are frequently mistaken for the true hanging or footwall in mining operations. At the time the veins were forming, it is conceivable that many of these secondary fissures served as channels for the ascending mineral-bearing solutions. These solutions permeated the mass of crushed country rock between the secondary fissures and replacement of the rock fragments by quartz was begun, each rock fragment, surrounded by a film of the replacing solution, becoming a center of attack. In some places, the process continued sufficiently long to replace completely the rock fragments by quartz or metallic sul-

[12] *Op. cit.*, p. 158.

phides. In the great majority of the quartz veins, however, replacement ceased before all of the fragments had disappeared, so that they are now preserved as inclusions. It is admittedly hard to reconcile the angularity of many of these inclusions with the idea that they have been developed by replacement. If replacement proceeds at a uniform rate, there can be no reason why an angularity that existed at the initiation of the process might not be preserved. That angular fragments of wall rock characterize the filling between the fissure walls may be observed at innumerable places where quartz occurs in only minor quantities and where the principal fissure filling consists of the fractured country (Plate X., *B*). The thin streaks of country rock that lie parallel to the walls in many cases are undoubtedly films of what once was gouge developed on one or another of the secondary fissures. The well-known impervious character of gouge might have prevented its replacement but permitted the wall rock on either side to be vigorously attacked. In this way, as the process of replacement continued, such bands would be left behind and ultimately be found lying one or more inches from the walls of the quartz vein. A similar explanation might well be applied to the trains of small angular fragments of wall rock that also lie parallel to the vein walls. Not infrequently one finds aggregates of rock inclusions so arranged as to give the appearance of preserving, by broken outline, traces of larger fragments of wall rock of which they were once integral parts. Such an instance is shown in Plate XI., *A*. In dealing with rocks which have no distinct schistosity or bedding, it is naturally impossible to state positively that groups of fragments, such as those that have just been described, once formed parts of a larger mass, the outlines of which still appear to be preserved. Nevertheless, careful examination of such occurrences can not fail to impress one with the fact that they are indeed merely the remnants of a larger rock mass that has been nearly completely replaced by quartz or calcite. That such an interpretation is perhaps justified is suggested in the case illustrated in Plate XI., *B*. This is a photograph of a quartz vein at the point where it is divided by a sharp

tongue of rock. The rock is granodiorite and easily recognized as such in the thick portion of the wedge which splits the quartz. At the end, however, where the rock comes to a thin edge, the original character of the rock has been almost completely destroyed. A striking feature, not well brought out in the photograph but clear to be seen by one on the ground, is that there is a nearly uniform gradation from the partly altered granodiorite to the almost completely altered rock, at the point of the wedge. The thin end is traversed by vein quartz of such irregular form that the different bands could hardly be called veinlets. The tip of the wedge has every appearance of being almost completely replaced by vein quartz.

The microscope has confirmed the field evidence in all cases. Although contacts of included fragments of wall rock with quartz may appear sharp in hand specimens, the microscope shows the rock to be irregularly penetrated by vein quartz. The rock inclusions, whether granodiorite or diabase, are usually greatly altered and consist of sericite, calcite, and chlorite. The quartz near the contact frequently encloses flakes of sericite or chlorite that have every appearance of being residuals of larger areas of altered rock that have been replaced by quartz. The same description applies to calcite when it occurs with quartz as vein matter. Vein quartz, when seen under the microscope, frequently has a dusty or cloudy appearance and it is often difficult, when examined with ordinary light, to distinguish it from the greatly altered rock fragments with which it is in contact. It is only with crossed nicols that the quartz stands out clearly in contrast with the altered rock. It is believed that this "dusty" appearance of vein quartz is due to the partial preservation of the original texture of the replaced rock by remnants or unreplaced particles of original minerals or of their alteration products. Sometimes offshoots from the main body of quartz penetrate rock inclusions as veinlets a few tenths of a millimeter in width and expand to larger areas with curved irregular boundaries separating them from the rock. Many other instances might be cited where replacement of included fragments of wall rock is clearly

indicated. This evidence in itself might not be sufficient to justify the conclusion that the gold-quartz veins were formed by replacement, but taken in connection with the field evidence with which it is in entire agreement, such a conclusion seems to be inevitable.

Although the facts that have been presented seem best to be accounted for by the replacement hypothesis, it is recognized that other processes may have combined to bring about the results that can be now observed. Unquestionably open spaces existed in portions of many of the fissures before the introduction of the quartz and they were probably filled with gangue and ore deposited by mineral-bearing solutions. It is not so easy to admit igneous intrusion as a process of vein formation which operated in conjunction with replacement. It is conceivable that replacement might take place in connection with the intrusion of veindikes, but where replacement appears to have been the predominating process, veindikes could hardly have played a minor part. Although at many places the appearance of the veins suggests that they were intruded as veindikes, the conflicting evidence is too strong to justify the acceptance of this hypothesis. I believe, therefore, that the veins were formed by the replacement of wall rock by quartz, calcite, and metallic sulphides and that subsequent fracturing of the vein filling permitted the introduction of later solutions which deposited the gold.

LITCHFIELD,
CONNECTICUT.

## *DISCUSSION.*

*Mr. Bateman:* I should like to add a word of appreciation for this paper that Dr. Howe has presented to us. The earlier and classical work of Lindgren has made Grass Valley one of our outstanding examples of gold quartz deposits. Consequently any further information in regard to this camp contributes not only to our knowledge of an interesting deposit in itself, but to the science of ore deposits in general. We are particularly fortunate in having summed up in this paper the results of several years geological work carried on at this mine by one whose keen conclusions were tempered by the steadying influence of a personal operating interest in the property. The conclusions, also, had that rare opportunity of being checked again and again by later field work.

The quartz veins of Grass Valley have long been considered to have been formed in large part by the filling of open cavities. Therefore, Dr. Howe's evidence of the part played by the process of replacement in the emplacement of these ore bodies is an interesting contribution to our knowledge of this type of deposit. It recalls to mind Dr. Stillwell's advocacy of replacement for the somewhat similar gold quartz veins of Victoria, Australia. I had an opportunity, through the kindness of Dr. Howe, to see some of the specimens and thin section which he brought back and the inspection of them left conviction with me of the soundness of his thesis of replacement origin.

I was particularly pleased to note Dr. Howe's reference to the angularity of the included fragments left by replacement—an angularity clearly shown by his lantern slides—because of the bearing it has on the brief paper I presented a few minutes ago on "Angularity in Replacement Deposits." They give support, independently arrived at, of the conclusion I tried to present to you.

Of no less interest is Dr. Howe's carefully worked out data in regard to the localization of the ore shoots of the North Star Mine. The cause of ore shoots is one of the most baffling problems of economic geology and we welcome any light that may be shed upon it. Dr. Howe's simple structural explanation carries plausibility and should open our eyes for the possibility of similar explanations elsewhere.

Another point that I was glad to hear discussed was the author's explanation of the peculiar banding so characteristic of this type of gold quartz vein and its relation to the sequence of mineralization, with the gold a later introduction along with galena and calcite.

I think we all owe thanks to Dr. Howe for the careful work he has done at Grass Valley and for presenting before us his results so clearly and concisely.

*Mr. Lindgren:* It was great pleasure to listen to Dr. Howe's paper. I left Grass Valley in the summer of 1894 and have not seen the place since and with all these developments coming along in the successive years, it was clear that there was much to be learned about the district and I was pleased and delighted that Dr. Howe has taken up the subject. I agree fully with the standpoint that Dr. Howe has taken. I agree that there has been replacement. I would not agree with the proposition that no filling has taken place. I have a vivid recollection of visiting the Rose mine in the center of Grass Valley, and of going there and putting my head and shoulders in a cavity two or three feet in diameter and finding it filled with fragments of country rock coated over with quartz crystals. On each were attached beautiful little crystals of pyrite. It seems to me that it was an open vein. It was a distinctly fractured

mass. One could see the fracture, perhaps two or three feet long, and a foot or so in depth, and it left an impression upon my mind that is difficult to eradicate.

*Mr. Spurr:* I visited Grass Valley some years ago, and examined several of the mines there. They all showed the phenomenon of auriferous sulphides which are later than the bulk of the quartz and which occur in cracks and fissures in the quartz; and where these later sulphides are abundant, oreshoots are formed. The Grass Valley type of vein is the typical deep-seated gold-quartz vein, almost uniform the world over; and the phenomenon of auriferous sulphides later than the mass of the quartz is characteristic of all of these veins which I have seen. The extraordinary thing would be not to find veins which show this phenomenon, which Mr. Howe describes for the North Star vein, but to find a vein of this type which does not show it. The Porcupine ores, in Canada, afford an example, recently described; the Mother Lode ores in California also conform to the rule. But in all cases these subsequent sulphides are practically confined to the quartz vein, or at the most penetrate and replace the walls, as in the Porcupine and Mother Lode districts. Some of the gold and sulphides are intercrystallized and contemporaneous with the quartz. This typical and fixed relation indicates to me that the sulphides are a final crystallization of the gold-quartz magma, their period of crystallization overlapping that of the quartz. This gold-quartz magma, at Grass Valley or elsewhere, I believe to have been injected as a veindike, as a pegmatitic veindike would be injected. Indeed, I hold that the gold-quartz veindike is a phase of the pegmatite veindike series, and that the demonstration of that relation is satisfactory and complete. As to the evidence of replacement and solution of included fragments in the quartz which Mr. Howe has observed and taken as a proof of the evidence of the formation of the whole vein by replacement, I hold this conclusion to be a logical *non sequitur*—the fact does not indicate the conclusion. A still longer logical jump is Mr. Howe's conclusion that since (as he assumes) the vein was formed by replacement, the agent was "thermal waters." I see no logical justification for this conclusion. The trouble seems to be in lack of knowledge of magmas, and in the assumption that they do not effect replacement. Fragments included in pegmatite dikes, however, often show replacement by the inclosing magma; and the same is true of many igneous rocks. In granite, the replacement of included fragments by the magma is a phenomenon commonly observed. We must not fail to recognize the same or like processes through the difference of words. In granite the process is often spoken of as "assimilation." The corrosion, absorption, assimilation or replacement of inclusions in the gold-quartz veins may commonly be ob-

served. In general, fragments which have lain longest in the fluid magma undergo most attack: those which were picked up not long before the freezing are relatively unattacked. Both types may be recognized in the photographs which Mr. Howe has put on the screen.

Since the evidence of replacement offered by Mr. Howe is identical with that which may be observed in pegmatites and granites, we should, on the basis of his reasoning, conclude that pegmatites and granites originated by replacement, and through the effects of "thermal waters."

In my opinion, the gold-quartz veins are as typical a magmatic type of veindike (having a constant mineral composition and crystallization sequence) as are the quartz-feldspar (alaskite) pegmatites.

*Mr. Howe:* I have been very much interested and pleased with this discussion because one of the objects I had in giving the paper was to secure an expression of the opinions of others regarding this not unusual type of gold-quartz veins. I have come to the conclusion that replacement best explains the origin of the quartz veins but I have recognized that other processes may also have been effective. I can not admit that all of the veins were formed by the filling of preëxisting open spaces, yet some open spaces undoubtedly existed and vein formation of the kind believed to be peculiar to filled open spaces may be observed at a number of places in the Grass Valley district.

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# CALIFORNIA OIL FIELD WATERS.

CHASE PALMER.

THE oil fields on the west side of San Joaquin Valley yield three types of water: (1) saline waters containing sulphates as their principal salts; (2) saline waters containing large amounts of chlorides; (3) alkaline carbonate waters having notable amounts of alkali carbonates. All the waters are mixtures of several salts in solution, but it is possible to distinguish them according to the prominence of their acid radicals. To avoid confusion that might possibly arise in the comparison of mixtures, each type of water will be expressed in terms of a single salt taken as representative of that water.

*Type 1. Sulphate Waters. Representative Salt, Sodium Sulphate* ($Na_2SO_4$).—Within the oil field limits sulphate waters, the normal ground waters of the west side oil fields, extend downward to a short distance above the oil measures; outside the oil field limits they often extend to much greater depths. They are recent waters whose properties are acquired chiefly from soluble salts ready made, such as would be deposited in areas having a limited supply and restricted outlet. The source of the sulphates is in the Coast Ranges where there are many deposits of gypsum and gypsite. The rocks also contribute magnesian minerals changing easily into soluble magnesium salts, which also are carried down through the oil fields and eastward into San Joaquin Valley. The properties acquired by direct action of the waters on the valley sediments are subordinate to the contributions received from higher levels. Two well waters east of Coalinga typify the kind of ground waters found in that part of the Valley, and the prominent part taken by sulphates.[1]

*Well No. 1.*—Sec. 32, T 19 S, R 17 E. Depth 250 feet.

[1] Chase Palmer, Examiner.

| | Parts per Million. | Reacting Values mg. H per Liter. |
|---|---|---|
| Sodium | 378 | 16.40 |
| Calcium | 196 | 9.80 |
| Magnesium | 182 | 15.00 |
| Sulphate | 1504 | 31.28 |
| Chloride | 223 | 6.26 |
| Bicarbonate | 135 | 2.22 |

*Chemical Character.*

| | |
|---|---|
| Primary salinity | 39.8 |
| Secondary salinity | 54.6 |
| Secondary alkalinity | 5.6 |
| | 100.00 |

*Well No. 2.*—Sec. 11, T 20 S, R 17 E. Depth 1,200 feet; perforated 400–600 feet.

| | Parts per Million. | Reacting Values mg. H per Liter. |
|---|---|---|
| Sodium | 258 | 11.20 |
| Calcium | 134 | 6.67 |
| Magnesium | 118 | 9.70 |
| Sulphate | 1023 | 21.28 |
| Chloride | 102 | 2.88 |
| Bicarbonate | 124 | 2.04 |

*Chemical Character.*

| | |
|---|---|
| Primary salinity | 40.6 |
| Secondary salinity | 51.6 |
| Secondary alkalinity | 7.8 |
| | 100.00 |

Well No. 2 is 3 1/2 miles southeast of well No. 1 and each of them is more than a mile east of the foothills.

In the sediments of the outlying districts organic compounds containing sulphur, in process of decay and oxidation, as well as inorganic sulphides, such as iron pyrites ($FeS_2$), oxidizable under atmospheric influences are probably adding sulphates to the ground waters. An outstanding chemical property of sulphate radical ($SO_4$) is its stability, and the resistance which it offers to separation of oxygen from sulphur is so strong that sulphates are not valued as oxidants.

*Type 2. Chloride Waters, Representative Salt, Sodium Chloride* ($NaCl$).—Chloride waters, or brines, occupy a low position in the oil measures and are closely associated with the oil. Geological evidence points to a marine origin, so that the brines appear to be remnants of ancient sea waters entrapped in the rocks when they were laid down. Thus oil field brines are really older than the rocks that now contain them.

In respect to position and origin, waters of types 1 and 2 are independent of each other.

*Type 3. Alkaline Carbonate Waters, Representative Salt, Sodium Carbonate* ($Na_2CO_3$).—These waters are widely distributed throughout the oil measures, being found not only associated with the oil, but also at some distance from the oil. They are generally believed to occupy a middle position lying between the normal sulphate waters above and the chloride waters beneath. The alkaline carbonate waters of the oil measures are much more concentrated than are the alkaline carbonate waters of rivers, lakes and shallow wells in areas of granitic rocks all over the world, and this high concentration is naturally due to restricted circulation in the oil measures during a very long period of time. They are efficient chemical reagents, serving to counteract the acidic, or corrosive, tendencies of the chloride waters, and acting also as cleansers of the oil by removing certain undesirable organic products—a preliminary cleansing process, like the neutralizing process used afterwards in the refinery.

## ALKALINE SULPHIDE AND CARBONATE WATERS.

### *Hoefer Hypothesis.*

The origin of the alkaline carbonate waters of the oil measures has always been uncertain, but the opinion now generally held is that they are meteoric waters, in particular, sulphate ground waters changed into carbonate waters by complicated chemical reactions between sulphate waters and constituents of petroleum. This view has been put forward repeatedly and supported by plausible arguments, so that practically it has become a doctrine of the petroleum production industry. The object of this article

is to present a few facts hitherto not considered in relation to petroleum hydrology, and from them to offer a more acceptable explanation of the source of the alkaline sulphide waters, and also of the origin of the alkaline carbonate waters which are closely related to them in the oil measures. According to the current doctrine the manner in which the conversion of a sulphate water into a carbonate water is supposed to take place is explained by recourse to the hypothesis that hydrocarbons from the oil, acting on the sulphate salts dissolved in water, reduce sulphate ($Na_2SO_4$) to the corresponding sulphide ($Na_2S$), while carbon dioxide ($CO_2$) and water ($H_2O$) are formed at the same time.

The parts supposed to be played by the various substances are expressed by the following conventional equation:

$$Na_2SO_4 + CH_4 = Na_2CO_3 + H_2O + H_2S,$$

or

$$Na_2SO_4 + CH_4 = Na_2S + 2H_2O + CO_2.$$

The solution now containing both alkaline sulphide ($Na_2S$) and alkaline carbonate ($Na_2CO_3$) is supposed to receive from unspecified sources further additions of carbon dioxide until all the sulphide is driven out of the water, when the transformation of a sulphate ground water into a true alkaline carbonate water is complete.

The reaction is expressed thus:

$$Na_2S + H_2O + CO_2 = Na_2CO_3 + H_2S.$$

This hypothesis of a subterranean change of a sulphate water into a carbonate water mixed with a sulphide water was proposed by H. Von Hoefer.[2] Accordingly, solutions of glauber's salt, epsom salt and gypsum are pictured as oxidants, capable of burning up hydrocarbons underground, forming the usual products of combustion, carbon dioxide and water.

Several years later G. S. Rogers[3] adopted Hoefer's hypothesis

[2] Engler and Hoefer, "Das Erdoel," Band 2, S. 28, 1909.

[3] Rogers, G. S., "Chemical Relations of the Oil Field Waters in San Joaquin Valley," U. S. Geological Survey Bulletin 653, 1917. "The Sunset-Midway Oil Field, California," Part 2, "Geochemical Relations of the Oil, Gas and Water," U. S. Geological Survey, Prof. Paper 117, 1919.

unreservedly and used it as a basis of classification of California oil field waters. The sulphate reduction hypothesis forces the conclusion that the alkaline carbonate waters within the oil measures are sulphate ground waters, more or less altered by oil, the degree of alteration being determinable by the proportion of residual sulphate in the waters of the oil measures. It should be stated that no experimental evidence worth mentioning is on record that it is possible for a sulphate ($Na_2SO_4$) to be reduced to a sulphide ($Na_2S$) under conditions prevailing in oil fields. Near the top of the oil measures, however, in a belt between the normal sulphate ground waters and the alkaline carbonate waters, strong sulphur waters are often found, and the position of these sulphur waters has been taken as evidence of the actual existence of waters in a state of transition from waters of the sulphate type to waters of the alkaline carbonate type. According to the hypothesis all the free sulphur and sulphur compounds evolved from the transitional sulphur waters are products imported into the oil measures, or left at the border.

An established geological fact is that natural waters acquire their properties largely by chemical reactions between the minerals of the rocks and the waters in contact with them, and in any geochemical classification of waters this fact should be duly recognized. In the classification of oil field waters proposed by Rogers the possibility of chemical action between rock minerals and water is ignored; the only substances presumed to act chemically on one another being hydrocarbons of the oil and gas from the oil measures and the chemically inert constituents of ground waters which for ages have been kept away from the oil measures by an impervious barrier.

### *Objections to the Hypothesis.*

*Thermochemical.*—Hoefer's assumed reduction of sulphate ($SO_4$) to sulphide (S) in oil field waters is analogous to what is known to take place in the famous LeBlanc process of soda manufacture. In that process an intimate mixture of sodium

sulphate and charcoal is heated in a furnace kept at a temperature of 1,000 deg. C. Reduction takes place thus:

$$Na_2SO_4 + 2C = Na_2S + 2CO_2.$$

Reduction of sulphate to sulphide is not spontaneous: the reaction is endothermic, so that it must be forced by continual application of external energy. Heat is necessary to restore to the sulphur the chemical energy given up in exchange for oxygen when the sulphur was oxidized to sulphate. In other words, reduction of sulphate to sulphide is a fire process, and, in absence of proof to the contrary, it may be accepted that sulphates are not reducible to sulphides in oil field waters. Evidently Hoefer takes no account of an important principle of thermochemistry. It is apparent that the sulphide waters of the oil fields are formed in some other way, and that the sulphur in them is from some other source.

*Geochemical.*—A report on Huntington Beach Oil Field recently issued by the California State Mining Bureau [4] is of more than local importance, for the descriptions of conditions there throw light on the source of the alkaline carbonate waters within the oil measures, not only of the Huntington Beach Field, but also of other oil fields as well. The following descriptions of conditions of the field are adapted from that report. Four different water zones occurring below the first oil-bearing measures have been recognized. In descending order they are Bolsa, Copeland, Brown, and Pearce, and their stratigraphic positions are given in detail in the California report referred to. The data on the character of waters in Pearce area here offered are adapted from the analytical section of the report of one of the areas.

[4] Report on Huntington Beach Oil Field, including geochemical relationship of waters, J. B. Case, V. H. Wilhelm and M. A. Grizzle, Summary of Operations of State Oil and Gas Inspector, vol. 9, No. 6, 1923.

CHARACTER FORMULAS.

*Reacting Values in Per Cent.*

| | Bolsa. | Copeland. | Brown. | Pearce. |
|---|---|---|---|---|
| Sodium | 44.37 | 45.50 | 48.08 | 46.94 |
| Calcium | 1.94 | 2.70 | 1.24 | 1.93 |
| Magnesium | 3.03 | 1.40 | 1.16 | 0.83 |
| Sulphate | 0.03 | 0.12 | 0.02 | 0.05 |
| Chloride | 47.68 | 49.00 | 48.99 | 43.49 |
| Bicarbonate | 2.59 | 1.40 | 1.15 | 6.36 |
| Total reacting values mg. H per litre | 987.4 | 758.4 | 767.8 | 829.7 |

*Chemical Character.*

| | Bolsa. | Copeland. | Brown. | Pearce. |
|---|---|---|---|---|
| Primary salinity | 89.5 | 91.5 | 94.8 | 87.1 |
| Secondary salinity | 5.9 | 0.7 | 3.2 | 0.0 |
| Primary alkalinity | 0.0 | 0.0 | 0.0 | 7.5 |
| Secondary alkalinity | 4.0 | 1.5 | 1.6 | 5.5 |

To visualize the concentration of these brines in absolute amounts, the chlorides and bicarbonates are recalculated into parts per million. Their relative corrosive tendencies are also given.

| Waters. | Chlorides. | Bicarbonates. | Corrosiveness. | Depth in Feet (Approx.). |
|---|---|---|---|---|
| Bolsa | 16,726 | 1,560 | Strongly corrosive | −2,600 |
| Copeland | 13,156 | 609 | Mildly corrosive | −3,000 |
| Brown | 13,333 | 536 | Mildly corrosive | −4,250 |
| Pearce | 12,794 | 3,220 | Non-corrosive | −4,950 |

Probably all four waters, originally very corrosive brines (chlorides), became admixed with alkaline carbonate waters (bicarbonates), the relative neutralizing effect of which appears in the column "corrosiveness." The progressive reduction of corrosiveness with increasing depth and its complete removal from Pearce water point to a deep seated source of alkaline carbonate in all four waters. The top of Pearce water is described as a horizontal plane, all the underlying formations being more or less saturated with water, and it is reported that the bottom limit of the Pearce water zone has not yet been reached.

It is probable that the underlying formations contain minerals which yield alkalies to waters, and that the alkaline carbonate waters of the oil measures of this field are derived from deep-seated strata.

### COASTAL PLAIN GROUND WATERS.

An extensive investigation of the ground waters of the Coastal Plain in Los Angeles and Orange counties has been carried on, the object being to correlate the waters of wells in a given area, whereby to find clues to buried structure in places where surface indications are lacking.[5] Analyses of three well waters are offered here to show in general the kind of ground waters of the region. Sulphates are notably subordinate.

| Well. | Depth in Feet. | Residue Parts per Million. | Sulphates Parts per Million. |
|---|---|---|---|
| Seal Beach | 795 | 254 | 37 |
| Dominguez Hill | 327 | 332 | 54 |
| Near Torrance | 600 | 576 | 64 |

CHARACTER FORMULA.

| | Seal Beach. | Dominguez Hill. | Near Torrance. |
|---|---|---|---|
| Sodium | 41.5 | 16.3 | 16.7 |
| Calcium | 7.3 | 24.2 | 22.1 |
| Magnesium | 1.2 | 9.5 | 11.2 |
| Sulphate | 10.0 | 10.1 | 7.0 |
| Chloride | 6.6 | 6.8 | 20.5 |
| Bicarbonate | 33.4 | 33.1 | 22.5 |
| | 100.0 | 100.0 | 100.0 |
| Total reacting values; mg. H per litre | 7.6 | 11.2 | 18.1 |

*Properties of Reaction.*

| | Seal Beach. | Dominguez Hill. | Near Torrance. |
|---|---|---|---|
| Primary salinity | 33.2 | 32.6 | 33.4 |
| Secondary salinity | 0.0 | 1.2 | 21.6 |
| Primary alkalinity | 49.8 | 0.0 | 0.0 |
| Secondary alkalinity | 17.0 | 66.2 | 45.0 |
| | 100.0 | 100.0 | 100.0 |

[5] Chase Palmer, Examiner.

These three well waters indicate considerable variation in the ground waters in the Coastal Plain, and, since variations in the properties of waters are due to differences in the chemical nature of the rock minerals with which the waters come in contact, definite changes in rock formations can be traced by chemical examinations of waters in neighboring wells. In this way valuable information has already been secured concerning the location and axial direction of buried structures in different parts of the Coastal Plain.

*Sulphur Waters, Huntington Beach Oil Field.*—The California report already referred to states that above the heavy oil zone is a soft shale, or clay, with streaks of tar sands with sulphur water in contact with them. The depth is understood to be approximately two thousand feet below sea level. The sulphur waters can not be considered transitional waters formed by reduction of sulphate, because the ground waters above the oil measures are practically free from sulphate. The sulphur in the sulphur waters of Huntington Beach Oil Field must come from an entirely different source.

## ORIGIN OF OIL FIELD SULPHUR WATERS.

Organic sulphur compounds are common constituents of petroleum in California and elsewhere, and, like the other organic constituents of oil, so also are the sulphur compounds reservoirs of chemical energy. Furthermore, the sulphur itself, being in the state of sulphide, has its own stock of chemical energy in reserve. The oil, therefore, may be regarded as a propitious source of the sulphur found in oil field waters; and the following explanation is offered of the manner in which oil field sulphur waters can be easily formed.

A sulphur-bearing gas, carbon oxysulphide, evolved from the sulphur compounds of the oil, migrates to alkaline carbonate waters which decompose the gas and entrap its sulphur.

Carbon oxysulphide, also called carbonyl sulphide, has been known to chemists for more than half a century. In 1867 it was discovered as a gas issuing with water from a thermal spring at

Harkany, Hungary; later it was observed in a cold spring at Parad, also in Hungary, and it has been found in other sulphur springs. It is probable that the gas from all the springs is evolved from bituminous material. Bitumen is said to occur in spots in the vicinity of Parad, and Hoefer states that as early as the year 1818 traces of petroleum were observed in a spring at Parad. The gas seems to be widely distributed in nature, but, being easily changed to carbon dioxide and hydrogen sulphide, it is probably obscured by those two substances. Carl von Than,[6] who discovered the gas, set to work to obtain it artificially by mixing a dilute solution of a mineral acid with a solution of an organic compound containing carbon, nitrogen and sulphur. Carbon oxysulphide was evolved in a continuous stream which could be increased or diminished at will by warming or cooling the mixture. Carbon oxysulphide is well known to organic chemists, being a common by-product in chemical reactions involving organic sulphur compounds especially in neutral, or slightly acid solutions. In alkaline solutions it is rapidly decomposed forming alkaline carbonate and alkaline sulphide.

Carbon oxysulphide is the simplest compound of carbon, oxygen and sulphur, its molecule containing one atom of carbon, one of oxygen and one of sulphur. Its formula, therefore, is COS. It is a colorless and very inflammable gas, with a peculiar, sharp odor, which reminds one of hydrogen sulphide. It is slightly soluble in water, its solution decomposing very slowly to form hydrogen sulphide and carbon dioxide.

Thus:

$$COS + H_2O = H_2S + CO_2.$$

The following method shows how easily the gas can be formed from oil in contact with a brine. Hydrosulphocyanate, a liquid, formula HCSN, is dissolved in water and the solution slightly warmed. The dissolved substance and water react at once on each other forming carbon oxysulphide and ammonia.

The equation is:

$$HCSN + H_2O = COS + NH_3.$$

[6] *Annalen der Chemie und Pharmacie*, Suppl. Band 5, 236, 1867.

A small quantity of mineral acid, such as sulphuric acid increases the yield of carbon oxysulphide. The acid merely removes from solution the free ammonia which interferes with the continued formation of carbon oxysulphide. This method is a simple variation of the method used by von Than.

The brines associated with the oil, being hydrolyzable, have acid properties and are corrosive, and are, therefore, reagents favorable to the formation of carbon oxysulphide from organic sulphur compounds either alone, or in conjunction with organic nitrogen compounds which also are present in petroleum. Hydrogen sulphide in small amounts has been detected in the brines; this is to be expected and is in harmony with the proposition that one of the gases evolved from the oil is carbon oxysulphide. The greater part of the gas probably migrates upward in company with the other gases and continues with them until it meets alkaline waters, which decompose carbon oxysulphide quickly to form alkaline carbonate and alkaline sulphide, so that all the carbon and all the sulphur that have journeyed together in a simple gaseous compound are fixed simultaneously.

The reaction may be expressed thus:

$$COS + 2Na_2CO_3 + 2H_2O = NaHS + 3NaHCO_3.$$

It thus appears that a close relation exists between the alkaline sulphide waters and the alkaline carbonate waters of the oil measures, and also that the alkaline carbonate waters are the parent solutions.

Since the sulphur in these sulphide waters is traceable to the oil, valuable information of oil field conditions may be obtained from them. Owing to the extreme reactiveness of dissolved sulphides these waters are subject to rapid changes with the formation of several products, so that in the collection of sulphur waters special precautions must be used to prevent their decomposition. The samples should be treated with preservatives, and the number of containers required for the examination of a water depends on circumstances. Analyses of oil field sulphur

waters are of no value for geochemical purposes unless they show the condition of the waters as they occur in the earth.

### ORIGIN OF ALKALINE CARBONATE WATERS OF THE OIL MEASURES.

Just as a natural source of the sulphur in the alkaline sulphide waters has been found to be within the oil measures, so also within the oil measures the source of the primary alkalinity (sodium carbonate) of the alkaline carbonate waters may be confidently sought. Alkaline carbonate waters, free from sulphate, are not peculiar to the oil measures of California, nor to oil measures anywhere, and therefore they are not necessarily the result of chemical action between oil constituents and immigrant waters. On the other hand, waters buried with sedimentary minerals derived from granitic rocks react chemically with the minerals to form several soluble compounds prominent among which are the alkalies. These give to the solutions primary alkalinity as a distinguishing property.[7] Primary alkalinity in the waters of the oil measures is merely an index of the kind of rock material with which the waters have been in contact.

A correlation of river waters of Piedmont Plateau from Virginia to Georgia, and another correlation of waters of the Coastal Plain of the Gulf of Mexico westward into Mississippi have shown how persistent is the effect of granitic sediments in maintaining the primary alkalinity of surface streams, subject as they are to various disturbing influences.[8]

### SUMMARY.

1. The alkaline sulphide waters of the oil measures are not formed by the reducing action of hydrocarbons on sulphates of ground waters.

2. The alkaline sulphide waters are derived from alkaline carbonate waters; they are alkaline carbonate waters more or less

[7] Palmer, Chase, "A Deep Well at Charleston, S. C.," U. S. Geological Survey, Prof. Paper 90 H.

[8] Palmer, Chase, "The Geochemical Interpretation of Water Analyses," U. S. Geological Survey, Bulletin 479.

altered by absorption of a volatile sulphur compound emanating from the oil.

3. The known geochemical relation of alkaline waters to granitic rock minerals applies to the alkaline carbonate waters in the California oil fields which abound in mineral sediments from granitic rocks. These alkaline waters belong naturally to the formations in which they are found, having acquired their properties from the minerals of the local rocks; and the position of these local formations in a field determines primarily the position of the alkaline carbonate waters.

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# MAGMATIC CHALCOPYRITE, PARK COUNTY, MONTANA.

T. S. LOVERING.

A COPPER deposit studied in connection with a geologic survey of the Cooke City district, Montana, proved to be a magmatic segregation. Since such deposits are rare in the western United States,[1] a brief description is offered here. The deposit is at Goose Lake about ten miles northeast of the Yellowstone National Park, and is accessible by way of Gardiner and Cooke, Montana. The Copper King Mining and Development Company owns the property, but at present the mine is idle.

*Field Relations.*—Pre-Cambrian granite is cut by intrusives which are provisionally called Tertiary, as rocks of similar character intrude Neocene lavas about five miles to the southwest. The ore body occurs a few hundred feet from the edge of a gabbro stock consisting chiefly of diallage and bytownite. This gabbro is seamed by basic pegmatites containing large crystals of hornblende, magnetite, apatite, and plagioclase. The stock and the nearby country rocks are cut by a series of intrusives which show a progressive increase in acidity from the oldest to the youngest. The ore body appears to be a late phase of the magmatic differentiation which gave rise to the intrusives just mentioned, and so far as could be determined, it is the youngest

[1] For descriptions of similar deposits, see the following:

Calkins, F. C., "Occurrence of Nickel Ore in San Diego County, California," S. Bull. 640 U. S. G. S., pp. 77–82 (1916).

Turner, H. W., and Roger, A. F., "A Geologic and Microscopic Study of a Magmatic Copper Sulphide Deposit in Plumas County, California, and its Modification by Ascending Secondary Enrichment," ECON. GEOL., 9, pp. 359–391 (1914).

Knopf, Adolph, "A Magmatic Sulphide Ore body at Elk Horn, Montana," ECON. GEOL., 8, pp. 323–336 (1913).

McLaughlin, D. H., "Copper Sulphides in Syenite and Pegmatite Dikes," ECON. GEOL., Vol. 14, pp. 403–410 (1919).

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rock in the region. The activity of mineralizers may be inferred in the field from the abundance of pegmatites in the younger as well as the older rocks. When followed along their outcrop many of these coarse grained intrusives may be observed grading into the rocks which form their walls elsewhere. Large crystals of biotite, apatite, muscovite, and plagioclase occur in these later pegmatitic dikes and sills.

A granodiorite mass 1500 feet east of the mine is cut by nearly flat sheets of microperthite pegmatite. The development of these pegmatites as horizontal sills suggests that their intrusion occurred near the roof of a granodiorite boss.

Quartz is abundant as a gangue mineral in the lead-silver-zinc veins near by, but is of minor importance in veins farther south. It may be possible that as differentiation progressed in the liquid portion of the granodiorite magma, the mineralizers became concentrated enough to resorb the quartz, or at least keep it in solution at the temperature and pressure attending the intrusion of the microperthite pegmatites. Later fracturing would permit the escape of the quartz-laden solutions and this may explain the quartz gangues just described, and also the scarcity of quartz in a differentiate from a granodiorite magma.

*Petrographic Study.*—The ore body consists of a chalcopyrite syenite, and is made up essentially of the sulphide and a perthitic intergrowth of orthoclase and albite. Muscovite, biotite, apatite, and magnetite were noted as accessory minerals. Veinlets of muscovite, orthoclase, chalcopyrite, and apatite cut the perthite grains, but in places the contact appears to be gradational. The rock is fresh, and no evidence of hydrothermal alteration can be seen. The muscovite is medium grained, and since it does not resemble the sericite developed in typical hot water alteration, it is believed to be a magmatic mineral. Chalcopyrite surrounds and corrodes the feldspars or crosses them in veinlets that usually follow cleavage planes. These veinlets frequently show a second generation of feldspar contemporaneous with the chalcopyrite, but later than the perthite grains traversed by them. This is illustrated in Fig. 65. In the leaner parts of the rock where

chalcopyrite is sparingly represented, the orthoclase shows little tendency to develop euhedral shapes, but in the richer portions the

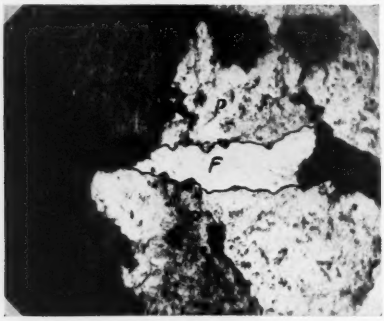


FIG. 65. Veinlet of chalcopyrite (black) and feldspar (*F*) cutting perthite grains (*P*). The veinlet has been outlined in black for greater distinctness. ×75.

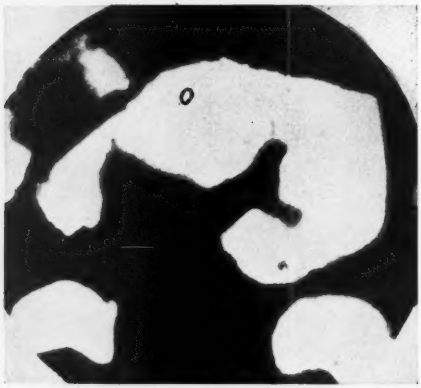


FIG. 66. "Porphyritic" ore. Orthoclase (*O*) phenocrysts surrounded and corroded by chalcopyrite (black). ×75.

texture resembles that of a porphyry, with a matrix of chalcopyrite and phenocrysts of orthoclase. The feldspar grains are

frequently subhedral and show evidence of having gained their present outline from the corrosion of formerly euhedral crystals by the sulphide. No reaction rims are present, and alteration of the feldspar was not noted. Fig. 66 illustrates the appearance of this "porphyritic" ore. In many cases muscovite crystals penetrate crystals of chalcopyrite, as shown in Fig. 67, and this may be

FIG. 67. Chalcopyrite (black) cut by euhedral crystals of muscovite (*M*). ×75.

taken as an indication that the sulphide is earlier than the mica.[2] While this criterion is not fully accepted by all geologists, it is believed by the writer that the muscovite in this ore is contemporaneous with or later than the sulphide. Minute tetrahedrons of chalcopyrite were observed in the interior of a grain of apatite; this indicates that the sulphide had started to crystallize before the phosphate. No pyrite was found in any of the specimens studied, and only very small amounts of magnetite, and occasional stringers of sphalerite. The magnetite is clearly earlier, and the sphalerite contemporaneous with or later than the chalcopyrite. Average samples of the ore assay 2.85 ounces of

[2] Tolman and Rogers, "A Study of the Magmatic Sulphide Ores," Stanford University, California, p. 30 (1916).

silver per ton, and up to one-tenth of an ounce of platinum per ton. No gold is present.

Summarizing we find: (1) No hydrothermal alteration can be detected. (2) Minerals associated with hydrothermal deposits, such as pyrite, carbonate, etc. are lacking. (3) The minerals of the deposit are those which are typically developed in magmatic deposits. (4) The occurrence of platinum in small quantities is corroborative of the syngenetic character of the ore. (5) The subhedral crystals of orthoclase, lacking reaction rims, surrounded and partially resorbed by chalcopyrite, are difficult to explain by any other hypothesis. (6) The penetration of chalcopyrite by muscovite indicates the early crystallization of the ore.

It is believed by the writer that the ore body of the Copper King Mine is due to progressive differentiation from a basic magma, and should be classed as a sulphide deposit formed at a late magmatic stage.

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# PRELIMINARY REPORT ON SOME COALS FROM SZE CHUAN, CHINA.[1]

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## INTRODUCTION.

RUMORS and reports of abundant coal in China have been prevalent for more than a century, but really very little is known of the value, properties, and geologic relations of the coals of most of the provinces of China.

Sze Chuan is a large far western province drained by the Yangtze Kiang and many of its tributaries. Its name means "four streams" in reference to four of these large feeders of the great river. The province has an area of 110,000–115,000 square miles and a population of 50,000,000 of people. Figures are at best only approximations, for China has never had an accurate survey nor a real census; the western boundaries of Sze Chuan are not lines but regions. Where Sze Chuan leaves off Tibet begins. The boundary is a border zone, occupied to be sure, but sometimes claimed by both, sometimes disclaimed by both, hence a zone where life and property are generally unsafe and where robbers at times flourish. Sze Chuan then may be described as an area as large as Ohio, Kentucky, and Indiana, with a population half as large as the whole United States proper.

The western half of the province is mountainous and rather youthful in general, the eastern half has some mountains and at the gorges of the Yangtze they are young, but in general this half is topographically mature to old. Lying in a belt of considerable rainfall and being crossed by the northern tropic, Sze Chuan is essentially an agricultural land and is rich in fruits, vegetables, grains, and oils.

[1] Presented at the Cincinnati Meeting of Section E, A. A. A. S., Dec. 29, 1923. Calorimeter tests by H. A. Williams, a chemistry student at Oberlin.

GENERAL GEOLOGIC RELATIONS.

Paleozoic rocks probably underlie most of the province; in the western half they are complexly folded, faulted, intruded, and deeply dissected. They have been subjected to several uplifts, hence to several cycles of erosion; the last uplift was relatively large and recent, so that these parts are rugged and little suited to agriculture or adapted to a large population until such time as the mineral wealth may be developed and an industrial age shall arrive. In these mountains are known coal, limestone, and the raw materials for iron, copper, lead, zinc, and silver, together with building stones, cements, and ceramic products. There probably are considerable areas of later rocks in this western half. However the coals to be discussed in this paper are largely in the eastern half, so our attention will now turn in that direction.

In this eastern half, the country long ago designated the "Red Basin," because of the predominant color of its rocks, relatively little geologic disturbance has occurred. After the Paleozoic rocks were laid down, the upper part of which contain the coals, and possibly after brief Mesozoic deposition, the rocks suffered their greatest deformation, resulting in long simple folds whose general direction is northeasterly. Six of these folds cross the country between Chengtu and Chungking and four more cross in the same general direction between Chungking and the Yangtze gorges. These gorges are carved in the massive limestones of two great folds which were peneplained and recently uplifted. There are two series of limestone in the section each about 4,000 feet thick. The river flows entirely across one fold and cuts deeply enough to expose pre-Cambrian granite in the core; thus developing four limestone gorges. It passes into the other fold far enough to cross the younger limestone.

The ten anticlinal folds mentioned previously are not nearly so large as those exposed by the gorges. In some cases they may have been folded as strongly but they are rarely 3 miles across and some are not more than one mile wide. In a few cases minor faulting is reported. Each anticline is a single, simple fold, one

to three miles wide, a hundred miles long more or less, nearly uniform in height, (*i.e.*, its axis rarely possessing perceptible pitch), and is always separated from its neighbors, perhaps by a width of five to ten miles of horizontal sediments between the folds, occasionally more than 20 miles. In this strip are Mesozoic sandstones and shales predominantly red and still nearly horizontal. The folds are maturely dissected and even often approach old age as do the horizontal strata between them. No pronounced topographic relief now exists although if the anticlines were restored they would have altitudes of 5,000–10,000 feet. The region containing these simple folds, from Chengtu and the western mountains to the gorges, has not been recently uplifted as in the case of the gorge folds and the western mountains, and thus stands in marked contrast to the rejuvenated areas to the east and west of it. Since there is no evidence of ponding of the river the uplift at the gorges was as slow as the down cutting.

When the Paleozoic strata of these ten folds were flexed into anticlines, the coal was also bent and erosion has exposed it on each side as a steeply inclined seam (in some folds two or three seams) that dips under the Mesozoic horizontal "Red Beds." The Chinese prefer to work inclined coal seams in order that they may draw it out on sleds instead of hoisting it from shafts. All mining is in the folded rocks and is carried on by crude native methods without the use of machinery. The coal measures of the anticlines may with reasonable certainty be expected to continue beneath the younger horizontal formations between the folds, but the mining of these beds must await more modern methods. At present hundreds of small mines occur along the flanks of the folds and furnish coal for the local smithy, for some small iron furnaces, for pottery and roof tile burning, for brick making, for manufacture of coke and for domestic consumption.

## THE COALS.

Of the 17 samples of coal considered in this paper, part were collected (see Fig. 68) by the author, and part by the Chinese and donated by the curator of the Museum of the Government

Technical College at Chengtu, the capital of Sze Chuan. None of the samples were collected by the most approved methods; representative pieces were chosen from baskets of coal as they came from the mine. In the samples collected by the Chinese there may have been a tendency to obtain a "best piece" but there is no reason to believe that there is not much more coal in

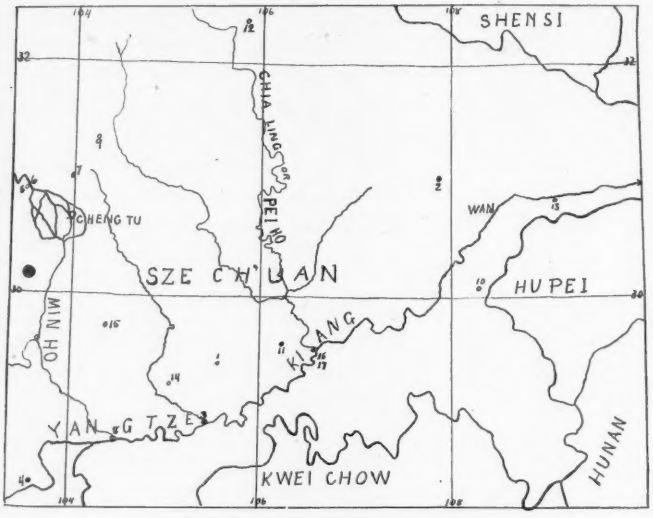


FIG. 68. Map of portion of Sze Chuan and adjoining provinces. Numbers correspond with the numbers of the coals in the text.

each mine as good as the sample taken. That none of these coals contain sulphur in detectable quantities does not establish the absence of sulphur in all the coal of the bed sampled. It does mean, however, that by reasonable hand picking, quantities of coal could be had with a similarly low sulphur content.

Some of the samples were fragments of about a pound. Those furnished by the museum usually weighed an ounce or so. The localities from which each came are indicated on the map by numbers.

Though it might be inadvisable to run tests or publish a paper on, say, Ohio coals, sampled and tested as were these coals, it has seemed best to make the most of these Chinese samples; first, they are the only samples and analyses available, so far as known, from the Sze Chuan province; second, many people are asking for actual information about coals of China; third, so far as these records go they are reliable. One understanding the nature of the samples and the character of the tests made, can make allowances for results, and still have much information until now not available.

*The Tests.*—Each sample was roasted in a bulb closed tube and its volatile and residue studied. Relative amounts only were ascertained; no weights or volumes were measured. Gases were burned, litmus tests of gases and water were made, odors sought, tars were examined as to color, consistency, and quantity. The coke or residue was examined with a lens to learn its character. Splinters of coal were tested in the flame for quickness of ignition, fusibility, or smoke. Both closed tube residue and fresh coal were pulverized and burned on platinum foil to discover the character and abundance of ash. No calorimeter tests were run, except on the last five. On these the B.t.u. were determined by the bomb-calorimeter. No ratios of fixed carbon to volatile material were established. Such tests are more costly and time consuming than those we have made, and the results of the more elaborate tests would vary from place to place in a bed of coal. It was therefore decided that such samples as these would scarcely warrant the extra work and expense in view of the fact that such accuracy of result might not apply to the coal as a whole.

*Summary of Results.*—Of the 17 samples tested, 12 coked in good shape, 5 would not. Of the 12 coking coals, 7 gave a firm clean coke, and 5 gave a fluffy, fragile coke. Apparently all the coking coals but one could be handled in a modern byproduct oven. That one is hard and does not fuse, but its lumps retain their shape on coking without melting. The coke seems to be of excellent quality. The coals producing the fragile, fluffy cokes fuse rather freely.

Each coal gave ash sparingly, except number 17. No ash fused to a clinker, save this last one, but two others tended to fuse a little; all others gave white to gray powder save two. Of these two, one was brown and one pink.

Of the 17 samples 2 are cannel coal, 3 subanthracite, and 12 bituminous. Both cannel coals coked well, one gave a firm, the other a fragile, product. None of the samples gave any perceptible sulphur odor, suggesting a universal low sulphur content. The gray to white ashes correlate with the sulphur findings regarding the absence of pyrite. Six coals gave a detectable ammonia odor, and 8 beside the 6 gave an alkaline reaction to litmus paper; two were neutral and one gave a decided acid reaction in its gas and water.

Nearly all yielded a good supply of combustible gas except the three subanthracites; and 13 yielded tar. These tars were usually brown and fluid but one was stiff even when warm. Judging from the color, two samples yielded toluene and benzine in their gases.

Only one of these coals is too crumbly to ship. The run of mine is lumps of firm, handsome coal, except one near Chungking. This coal is all in small fragments and resembles our "slack" of the trade.

The coal seams vary in thickness from 3–6 feet. The Chinese will work a bed as thin as 2 ½ feet. All the samples came from beds at present being worked.

### DISTRIBUTION, OCCURRENCE, AND PROPERTIES.

In the accompanying table I are given in condensed form the essential properties of each of the samples. The distribution and occurrence of these samples are given under the subheadings, and their location is shown on Fig. 68.

*Coal No. 1.*—Um Chang (Jung Chang), a town among the folds about 35 miles north of Lu Chow.

*Coal No. 2.*—Sin ning or Sin ling. Sample comes from outcrops or mines in folds that are the continuations of the folds crossed by the Yangtze River at Chungking. (Compare with Coal No. 11.) If coal of

TABLE I.

TABLE I.

PROPERTIES OF SZE CHUAN COALS.

| Number. | Kind. | Gas. | Tar. | Ammonia. | Reaction. | Coke. | Ash. |
|---|---|---|---|---|---|---|---|
| 1..... | Subanthracite | Insufficient to ignite | Meager, good quality | Odor | Slightly alkaline | Yes, swells up. | Gray powder |
| 2..... | Bituminous | Much, burns freely | Runs freely, brown | Much | Strongly alkaline | Swells much, fragile, fluffy | White powder |
| 3..... | Bituminous | Meager | Scarce | Trace | Alkaline | No coke | Grayish powder |
| 4..... | Cannel | Small amount | Considerable brown, red | Trace | Alkaline | Loose, fluffy | White powder |
| 5..... | Cannel | Moderate | Present | Strong odor | Alkaline | Firm, solid | |
| 6..... | Bituminous | Much volatile, little combustible | Abundant | None | Strong alkaline | No coke | Meager white powder |
| 7..... | Bituminous | Abundant, probably toluene or Benzine | Oily | Notable | Alkaline | Fine, firm, porous | White powder |
| 8..... | Bituminous | Abundant | Abundant dark | None | Alkaline | Hard firm | White fluffy powder |
| 9..... | Bituminous to Sub-Bitum..... | Abundant | Oily liquid | Strong odor | Strong alkaline | Cokes readily, light, firm | White powder |
| 10..... | Subanthracite... | Meager | Abundant, dark stiff | None | Neutral . | Good but not fused | Gray powder |
| 11..... | Bituminous | Abundant | Abundant | None | Strong alkaline | Swells much, fragile, fluffy | Gray, fuses a little no clinker |
| 12..... | Bituminous | Abundant | Runs freely | Feeble odor | Neutral | Fluffy coke | Meager, white powder |
| 13..... | Bituminous | Small amount | Brown, meager | None | Strong alkaline | Bright, firm | Abundant white powder |
| 14..... | Bituminous | Much | Black, meager | None | Slight alkaline | Bright, shiny, fluffy, fragile | Slightly pink to gray powder |
| 15..... | Bituminous | Gas meager | Brown, free | None | Feeble alkaline | Firm but porous, shiny | White powdery |
| 16..... | Subanthracite | Abundant | Meager, reddish brown | None | Feeble alkaline | Poor Coke | White powder |
| 17..... | Subanthracite crumbly slack | Gas enough to ignite | None | None | Water strongly acid | No coke | White powder abundant |

this quality is continuous, as seems possible, all the way from Chungking north eastward 150 miles or more, it suggests an abundance of coal in the province.

*Coal No. 3.*—Said to come from Lu Chow on the Yangtze River nearly 100 miles above Chungking. There is no coal near this city. The strata exposed are all younger horizontal sandstones. The coal is probably from mines to north west of town about 20 miles.

*Coal No. 4.*—Lei po ting or Lu po ting a town 70–75 miles up Yangtze from Sui Fu, above the rapids, and in the mountains in the borders of Lo-lo (wild tribes).

*Coal No. 5.*—Kwan Hsien. About 40 miles up the Min or Si Ho from Chengtu; 4–5 seams of coal are worked extensively near this town in the south flanks of a gigantic anticlinal fold with a N. N. E.–S. S. W. axis. Coal at Mao Chow is apparently on the opposite or N. W. flank of the same anticline.

*Coal No. 6.*—Kwan Hsien. A sample very different from No. 5, but entirely possible for 4–5 beds are worked near here. Some beds furnish excellent coking coal which is coked and the product shipped by water in great quantities to Chengtu.

*Coal No. 7.*—Shih Fang, is about 20 miles due north from Chengtu just beyond the Chengtu plain and in the border mountains.

*Coal No. 8.*—Nyi bin (Sui Fu). Sui Fu is the old name but is best known. Nyi bin is the name given to the town when the Republic began. Anthracite occurs in the large fold 4–5 miles east of the city but no samples were taken. This sample was taken in a more gentle fold about one mile east of the city.

*Coal No. 9.*—Ngan or An Hsien, a town of importance about 60 miles north and 12–15 east of Chengtu. It is in the mountains where the strike of the structures is N. E.–S. W. and the beds may be correlated with those of No. 7 at Shih Fang.

*Coal No. 10.*—Shih Chu which means stone column with reference to residual rock structures in the near by hills. This place is off the Yangtze about 15 miles to the south and about as far from the Sze Chuan-Hupei border. It is down the river 100 miles in a bee line from Chung king.

*Coal No. 11.*—From Pi Shan in the first folds west from Chungking on the Chengtu road. This broad anticline is maturely reduced by stream erosion. Its continuation southward to the Yangtze River reveals two fine 6-foot seams of coal which are worked along the river near Li huang shih and Chiang K'ou.

*Coal No. 12.*—From Kwang Yuan in the far northern part of the province near the sources of Chia ling Ho the branch of the Yangtze that comes in at Chungking. This place is in very hilly land whose summits rise 2,000–3,000 feet above the river.

*Coal No. 13.*—From Ku lin to, a small river town on the Yangtze about midway between Wan Hsien and Kwei Chow Fu. A broad anticline a few miles to the south brings up the coal-measure rocks.

*Coal No. 14.*—From Shih Yen Chiao about 30 miles north of Lu Chou. Mines are opened in both sides of the fold and at two levels on each side. Enormous quantities, for production by hand, are carried away from these mines.

*Coal No. 15.*—From Huang Chia Ch'ang a town 30 miles east of Kia ting and 60 miles south of Chengtu. There are many mines about the town, in a maturely dissected, broad, regular, anticline.

*Coal No. 16 and No. 17.*—These two samples were taken from the mines in the folds south east and south of Chungking. The folds run N. N. E.–S. S. W. and are crossed by the Yangtze River below the city. They result in ridges with ragged crests some 2,000 feet above the valley floors or 2,500–2,800 feet above sea level.

No. 16 is the older lower bed and is 4–5 feet thick but was badly mashed in the folding.

No. 17 is the upper younger bed with shales and a heavy limestone between it and No. 16. This bed in places is scarcely more than a foot in thickness.

TABLE II.

CALORIMETER AND ASH TESTS ON COALS NOS. 13–17.

| Number. | Locality. | Heating Value B.T.U. | Per Cent. Ash. | Character of Ash. |
|---|---|---|---|---|
| 13..... | Kulinto | 12,202 | 10.48 | White, small tendency to clinker. |
| 14..... | Shih yen Chiao | 12,530 | 16.93 | White, very fine, slight tendency to clinker. |
| 15..... | Huang Chia Chang | 11,940 | 9.86 | White, very fine, slight tendency to clinker. |
| 16..... | South of Chung king lower bed | 12,707 | 7.56 | White, very fine, hardly any tendency to clinker. |
| 17..... | South of Chung king upper bed | 9,072 | 35.33 | White, tendency to form solid clinker. Resembles ash of pure carbon. |

## DISTRIBUTION AND MARKETS.

Every one of the ten anticlinal folds has coal. Each was crossed twice but no fold was followed. So far as the evidence goes the coal is essentially continuous along the folds. Beds may run out and new ones come in as in any coal field but it is believed that coal is generally exposed in the anticlines. This

means of course a wide distribution even from the present Chinese point of view. It places coal within easy reach of most of the people. Transportation is largely by river or in baskets on poles across men's shoulders. In the former method coal can be carried considerable distances cheaply, but when the river does not connect town and mine and the coolie is brought into service, or occasionally the donkey, transportation charges quickly become prohibitive. Roads are paths only, usually paved with slabs of stone a foot wide laid end to end and worn by thousands of feet but never a wheel. The nearest railroads are at Hankow, Yunnanfu and westward in Burma, no one of which reaches within hundreds of miles of the Sze Chuan provincial border.

But coal is present and other resources abound; the population is abundant, industrious, alert, conservative. The time will come when China will want this coal. It is reasonably certain that no foreign commercial development will arise which will remove it before China is ready to use it herself. She is coking the coal now in a crude way in many places to reduce transportation charges. Gases are all lost in the process.

Back in the western mountains of Sze Chuan northwest of Chengtu 40–100 miles, are other coal beds which the Chinese are working extensively. No samples were taken from these beds. Much coal is ingeniously coked near the mines and transported by boat to the city of Chengtu.

OBERLIN COLLEGE,
OBERLIN, OHIO.

# A TRANSVAAL SILVER–LEAD DEPOSIT.

PERCY A. WAGNER.

THE object of the present note is to describe a silver-lead deposit situated in the Central Transvaal and to endeavor to explain some rather remarkable features presented by its oxidized zone, and the relation of oxidation to climatic changes.

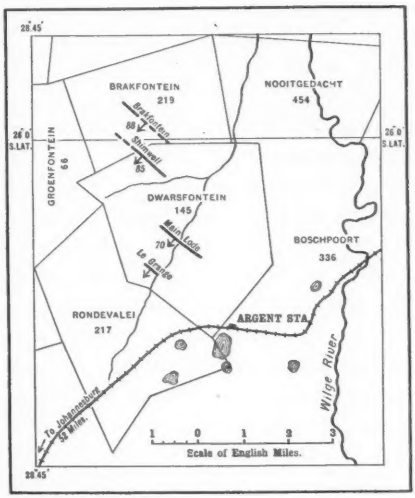


FIG. 69. Index map to show principal silver-lead veins near Argent Station, Transvaal.

The deposit in question is one of a series of roughly parallel galena-siderite veins that have been opened up on the farms Dwarsfontein, No. 145, and Brakfontein, No. 219, near Argent Station, on the Johannesburg-Witbank line, some 50 miles east of Johannesburg.

It was discovered in 1889 and exploited for some years by a company called The Transvaal Silvers Limited. Operations proved unprofitable on the whole and were suspended in May, 1894. It then lay idle until the middle of 1919, when the high price of silver and lead, at that time ruling, led to the reopening of this and some of the other veins of the area by the Transvaal Silver and Base Metals Limited.

An up-to-date concentrating plant and smelter were erected and during the past two years fairly considerable quantities of silver-lead bullion have been produced. At present developments at depth are causing grave apprehension. Very little workable ore has been opened up in recent months, and, unless there is a marked improvement in this respect, it is to be feared that mining and smelting operations will once more have to be discontinued.

Most of the ore won by the two companies named has been derived from what is known as the Main, or No. 1 Shaft, Lode. This the writer recently had an opportunity of studying. It is a well defined fissure vein that can be traced at the surface for a distance of about 5,000 feet. It strikes 50° west of north and the dip ranges from 45° to 80° to the southwest, the average dip being about 70 degrees. The thickness of the vein varies from 14 feet to nothing, the deposit giving out altogether in places. It has been opened up to a vertical depth of 750 feet.

The surrounding country is typical gently undulating High Veld made up of alterations of low grass-covered ridges or *bults* and broad flat-bottomed marshy valleys. The Main Lode cuts across a valley of this nature drained by a sluggish tributary of the Wilge River. The mean elevation is about 5,000 feet above sea-level. The topography is very mature. It is quite certain that there have been no appreciable changes in the level or configuration of the surface in recent geological times.

The annual rainfall is in the neighborhood of 30 inches, but fluctuates within wide limits, abnormally wet and abnormally dry seasons recurring at fairly regular intervals. Most of the rain falls during the period October–April. The remaining months of the year are practically rainless.

The country rock of the vein in the neighborhood of the No. 1, or Main, Workings is a medium-grained norite composed essentially of labradorite ($Ab_2An_3$), bronzite, diallage, and titaniferous magnetite. Apart from being finer grained, it is very similar to the more normal norite of the Bushveld Complex. Toward the southeast this norite graduates into a coarse grained bronzite-diallage-pyroxenite which forms the country rock of the vein at the No. 2 workings. The pyroxenite encloses tabular segregations of titaniferous magnetite. The norite, pyroxenite and titaniferous magnetite form part of a complex of igneous rocks, also including red granite and granophyric granite, which evidently represents an offshoot from the main Igneous Complex of the Bushveld lying to the north. In the No. 1 workings there have been struck a number of large bodies of a handsome pink porphyritic quartz-syenite of the *Aker* type. Its relation to the surrounding norite has not been established, but it is presumably intrusive in it.

### MINERALOGY OF THE PRIMARY ORE.

The deposit belongs as previously stated to the galena-siderite group of veins,[1] being mineralogically very similar to the more typical veins of the Coeur d'Alene District of Idaho so ably described by F. L. Ransome.[2] The primary ore contains the following minerals: galena, argentite, native silver, chalcopyrite, pyrite, pyrrhotite, zincblende, tetrahedrite (?) meneghinite (?) siderite, quartz, chlorite, and dolomite. It is, as a rule, roughly banded parallel to the vein walls, being made up of alterations of siderite and galena or of siderite-rich and galena-rich bands, through which isolated patches of chalcopyrite are irregularly scattered. Thin stringers of galena are also seen occasionally to cut across the banding. The zincblende is generally enclosed in veins or patches of fine-grained cherty quartz which is of later deposition than the minerals previously named.

The principal ore minerals are galena and argentite. The latter occurs as minute microscopic inclusions in the galena which

[1] *Cf.* Lindgren, W., "Mineral Deposits," pp. 595–598.

[2] Professional Paper, 62, U. S. Geol. Survey, 1908, pp. 90–140.

are only rendered visible by etching polished surfaces of that mineral with nitric acid. The inclusions are of rounded or irregularly elongated outline and up to 12. mm. in greatest length. They may very well, as suggested by Schneiderhöhn,[3] have been derived by ex-solution or unmixing in the solid, the ratio of silver to lead in the primary ore being practically constant. It averages slightly over 1 ounce of silver per short ton to each per cent. of lead, and there has been practically no variation in this ratio at depth. Thus the hand-picked ore from the 130-ft. level of the mine, shipped in the year 1892 by the Transvaal Silvers, Limited, averaged 71 per cent. of lead and 79.5 ounces of silver per short ton, whereas the ore developed on the 500-ft. level during the first quarter of the present year averaged 8.4 per cent. of lead and 8.8 ounces of silver per short ton.

*Galena.*—The galena is both coarse, and fine-grained. In the coarse variety cleavage faces indicate crystals up to one and a half inches across. The large cleavage surfaces are often bent and deformed as a result of movement in the plane of the lode, of which there is abundant evidence; the walls being in places horizontally slickensided. Much of the massive galena, moreover, exhibits a streaky or banded appearance, and the coarse-grained variety is often traversed by bands of the fine-grained. There can thus be no reasonable doubt that a part of the fine-grained galena has been derived from the crushing and recrystallization of the coarse-grained variety along fractures and planes of movement in the ore. But part of it cannot be explained. Thus the writer came across several isolated patches of galena, completely surrounded by siderite, itself showing no sign of fissuring or deformation, in which an irregular outer zone of fine-grained galena surrounds the core of the coarse-grained. The fine-grained galena is here evidently in its original condition. It should be stated that there is no difference in silver content between the coarse and finer-grained galena.

*Silver.*—As far as the writer is aware only one specimen of native silver has so far been found. It weighs about four ounces

[3] Schneiderhöhn, H., "Beobachtungen uber Entmischungsstrukturen in Sulfidischen Erzen," *Metall. und Erz.*, 1922, pp. 517–526.

and is composed for the most part of coarsely crystalline silver intergrown with galena and siderite. It was picked up in the crusher house and is in the possession of Mr. J. Ritchie, General Manager of the Transvaal Silver and Base Metals, Limited. The silver was found on analysis to be practically pure. Its relation to the associated galena and siderite shows that it must be a primary mineral.

*Chalcopyrite.*—This mineral is fairly uniformly distributed through the ore and becomes increasingly abundant at depth. It occurs in anhedra up to one inch across, often imbedded partly in galena and partly in siderite. Smaller anhedra are sometimes completely enclosed in large crystals of galena.

*Zincblende.*—Zincblende of dark brown color while almost invariably present, is not abundant in the Main Lode, but the ore of the Brakfontein Lode contains up to 10 per cent. of zinc.

*Pyrite.*—Pyrite also is not very common. It occurs for the most part in intimate intergrowth with chalcopyrite.

*Pyrrhotite.*—Thin stringers and plates of this mineral were noted in all specimens from the fifth level of the mine. It is very feebly magnetic.

*Meneghinite* ?.—According to Molengraaff[4] tetrahedrite is present in the ore. In the material collected by the writer the mineral could not be identified, but in some of the polished surfaces and thin sections of ore examined small patches and crystals of a grayish-white lead-antimony sulphide are fairly common. The crystals are columnar and striated lengthwise. The physical and chemical properties of the mineral point to its being meneghinite ($4\ PbS.\ Sb_2S_3$). As, however, the writer has no undoubted meneghinite on which to carry out confirmatory tests, its identity must for the present remain in doubt. Analyses of the ore prove that, in addition to antimony, it contains small amounts of arsenic. It is not known in what combination that element is present.

*Siderite* is the predominant gangue mineral. It is for the most part coarsely crystallized, occurring in interlocking anhedra up

[4] "The Geology of the Transvaal," p. 53.

to one and a half inches across. It is of a very pale yellowish-brown color and tarnishes rapidly on exposure. An analysis of the mineral, made in the Government Chemical Laboratory, Johannesburg, gave the following result:

| | Per cent. | | Per cent. |
|---|---|---|---|
| $SiO_2$ and Insol. | 2.8 | MgO | 6.05 |
| $Fe_2O_3$ | 0.20 | CaO | 0.85 |
| FeO | 47.80 | $CO_2$ | 39.50 |
| MnO | 2.90 | | |
| | | Total | 100.10 |

This shows that it is very near the *sideroplesite* of Breithaupt [5] which contains 12 per cent. of $MgCO_3$. It is also closely allied in composition to the magnesian siderite occurring in the cassiterite deposits of Rooiberg, in the Transvaal, which contains up to 20 per cent. of $MgCO_3$.

*Quartz.*—A certain amount of fine-grained cherry-white or grey quartz is always present. It sometimes contains vugs lined with colorless quartz crystals.

*Chlorite.*—The ore everywhere contains patches of dark green chlorite and is cut by thin stringers composed of that mineral. The vein itself is, moreover, almost everywhere bordered above by a tabular body of soft chloritic matter known as the "Dyke." This evidently represents hydrothermally altered, crushed country rock, the norite surrounding the vein being itself as a rule much chloritized at and near its contact with it. In places there is also a development in the footwall of the deposit of chloritic gouge interspersed with irregular patches of white quartz.

*Dolomite.*—The vein matter is in places intersected by later cross veinlets of greyish dolomite.

### PARAGENESIS OF ORE AND GANGUE MINERALS.

It is difficult to make out a definite sequence of ore and gangue minerals. It is evident, however, that part, at any rate, of the galena is later than the siderite which it replaces, the evidence of replacement being very clear in thin sections of the ore. Further,

[5] *Cf.* Dana, J. D., "A System of Mineralogy," p. 277.

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that chalcopyrite, pyrrhotite, and part of the pyrite are of earlier crystallization than the galena. Zincblende appears to be later than the galena in this deposit, but in the Brakfontein vein already referred to, where it is more abundant, it is earlier. The mineral taken to be meneghinite crystallized after the galena. Quartz is later than the siderite, and chlorite and dolomite are later than the sulphides.

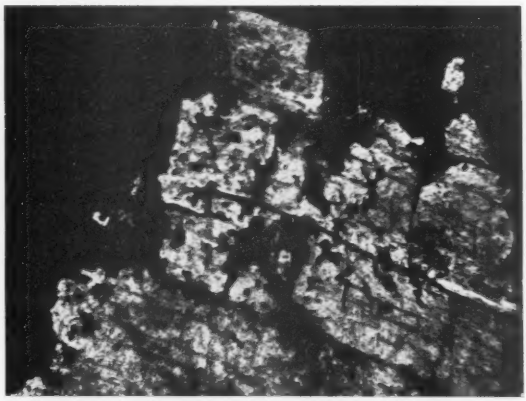

FIG. 70. Photomicrograph of a thin section of ore from the 5th level, Transvaal Silver and Base Metals mine, illustrating the replacement of siderite by galena (black). ×60.

CHEMICAL COMPOSITION OF THE ORE.

An analysis of a typical sample of mill ore, as sent to the treatment plant in the early part of 1923, is given below. It was made in the mine laboratory.

| | Per Cent. | | Per Cent. |
|---|---|---|---|
| Pb | 9.10 | P | trace |
| Cu | 0.44 | $SiO_2$ | 29.16 |
| As | 0.12 | $TiO_2$ | 0.26 |
| Sb | 0.46 | $Al_2O_3$ | 5.36 |
| Zn | 1.20 | CaO | 0.94 |
| Ag | 0.03 | MgO | 4.18 |
| Fe | 19.60 | $CO_2$ | 16.80 |
| Mn | 0.63 | O and combined water (by difference) | 8.75 |
| S | 2.97 | Total | 100.00 |

### DISTRIBUTION OF THE WORKABLE ORE.

The Main Lode has been opened up to a depth of 750 feet, but no workable ore has been found as yet below a vertical depth of 520 feet. An examination of the assay plans, on which thousands of assays have been carefully plotted, fails to reveal the existence of any definite ore shoots. The workable ore occurs in irregular patches surrounded by barren siderite, the distance between the individual patches increasing with increasing depth. The ore, as stated, has become richer in copper on the lower levels of the mine. There is thus just a possibility that at greater depth the poor silver-lead zone, in which the lower workings now are, will be succeeded by a more productive copper zone. It should be stated that some 30 miles to the northwest of the deposit under description there are exposed on the farm, The Willows, in diabasic rocks directly connected with the norite previously referred to, veins carrying argentiferous tetrahedrite and chalcopyrite in a gangue of siderite. They were at one time worked, and near the surface yielded some very rich silver-copper ore.

### ORIGIN OF THE VEIN.

It is not proposed to enter into a detailed discussion of the origin of the system of veins of which the Main Lode has so far proved the most productive. They are obviously related to the Igneous Complex of the Bushveld, and their composition is such as would be expected, according to the Zonal Theory of ore deposition, from their position in the peripheral part of an offshoot from that complex. At the other extreme are the pegmatitic and pipe-shaped tin deposits in red granite, situated in the heart of the main complex. Closely related to them, but occurring on a slightly higher horizon in granophyre, are the tin-tungsten-copper pipes of the Stavoren area. Linking these deposits with the more normal mineral veins are the cassiterite lodes of Rooiberg and Leeuwpoort, in which siderite, magnesian siderite, chalcopyrite, galena, and zincblende are present; these minerals being clearly products of the hydrothermal stage of ore deposition that suc-

ceeded the strictly pneumatolytic stage, during which cassiterite, wolframite, magnetite, specularite, quartz, orthoclase and tourmaline were deposited. It is quite possible that the original upper extension of the Rooiberg and Leeuwpoort lodes, long since removed by denudation, may have resembled those under discussion, or, at any rate, the tetrahedrite-chalcopyrite-siderite veins of The Willows, already referred to, which, as suggested, probably belong to a somewhat deeper zone than the galena-siderite veins.

From the foregoing it appears highly probable that the mineral-bearing solutions that gave rise to these latter veins emanated from the Red Granite of the Bushveld Complex, a rather fine-grained variety of which covers considerable areas on the northern part of the farm Brakfontein No. 219. The veins were clearly formed partly by fissure filling and partly by replacement under intermediate conditions of temperature and depth.

### THE OXIDIZED ZONE OF THE VEIN.

*Upper Part.*—The oxidized zone of the Main Lode, as already indicated, presents several remarkable features. Along some parts of its course the vein is capped with a gossan which in places projects slightly above the level of the ground. Along other parts there was no gossan, and partly altered galena actually came to the surface, or was found within a thin covering of soil. Speaking generally, the gossan-capped stretches mark the position of the poor sections of the vein, and those, where galena was found at the outcrop, the rich. The gossan consists mainly of a mixture of impure earthy or botryoidal limonite and quartz which are sometimes accompanied by iron-opal and chalcedonic silica. Parts of it are hard and compact, but, as a rule, it has a porous cellular texture. It is sometimes stained black with films of secondary manganese dioxide, but this is unusual. It usually contains only subordinate amounts of lead and silver. The lead minerals occur as crystals lining druses and cavities as crusts and irregular layers and patches. They comprise, in addition to residual galena, cerussite, anglesite, pyromorphite, vanadinite, massicot, minium, wulfenite (?), and crocoite.

Cerussite is by far the most abundant of these secondary minerals. It owes its origin partly to the alteration in place of galena, or, more correctly, of anglesite, and partly to the deposition of lead carbonate from descending solutions. The cerussite of the latter type occurs mostly in well-shaped crystals. Simple tabular forms, flattened parallel to the brachypinacoid, predominate, the complex penetration twins so common in the lead deposits of the Western Transvaal being conspicuous by their absence. The mineral is in places accompanied by powdery massicot, and is sometimes stained yellow by it.

Anglesite forms thin crusts encasing residual masses of galena, the anglesite being itself invariably surrounded by much thicker crusts of cerussite that has evidently developed from it. The anglesite thus merely represents an intermediate transitory stage in the ultimate carbonation of the galena. It is rarely visible and its presence can, as a rule, only be established chemically (by means of ammonium acetate).

The other lead minerals named are very rare. Minium was only noted in one specimen in which it occurs in admixture with earthy iron oxide. Wulfenite is referred to in early descriptions of the mine. A specimen of alleged wulfenite examined by the writer proved to be crocoite. Fine crystals of that mineral are fairly common in the gossan of the Shimwell vein, situated some distance to the northeast of the occurrence under description.

The lead minerals are accompanied by subordinate amounts of malachite. Azurite is also occasionally seen.

There is considerable uncertainty as to the form in which silver is present in the outcrop ore. According to early reports some of the residual masses of partly altered galena, found at the surface, assayed as much as 250 ounces of silver to the ton; or over three times as high as the richest primary ore. This points unmistakably to enrichment, but as none of the ore is available for examination it is impossible to say to what the enrichment was due.

In the normal gossan ore, which, as a rule, is poor in silver, the residual galena was found to contain the usual minute in-

clusions of primary argentite. They were evidently protected from oxidation by their hosts. How the silver occurs in the completely oxidized vein matter is not known. Neither the native metal nor cerargyrite could be identified. Leaching tests with ammonia, made in the laboratory of the Geological Survey, failed, moreover, to reveal the presence of any of the halides of silver. To confirm these tests a sample of oxidized ore, known to be fairly rich in silver, was submitted for examination to Dr. J. McCrae, the Government Analyst. His report on it is as follows:

> The sample submitted was finely crushed and well mixed. The material was found by dry assay to contain 0.14 per cent. of silver, equal to 41.2 ounces per short ton. 900 grams of the finely-crushed material were extracted with strong ammonia solution. The ammonia solution was acidified and the material causing the slight turbidity was collected. It was found to be mainly of a humic nature, but after getting rid of the humus a definite trace of silver was found to have passed into solution in the ammonia. This suggests that a portion of the silver exists as silver chloride or as a water-soluble silver compound, but the quantity of silver which passed into solution in the ammonia solution is estimated at about only 0.000005 per cent. I am of opinion that the silver contained in the rock is not present as silver chloride.

The yellow color of some of the cerussite suggested that it might contain silver carbonate. Careful chemical tests failed to reveal the presence of that component, and the yellow color was proved to be due to massicot. Further investigation is clearly needed.

*Middle and Lower Parts.*—Below the gossan or the residual surface ore there follows everywhere at a depth of from 20 to 25 feet an *enriched zone,* some 10 feet in depth, in which a considerable part of the lead is present as cerussite evidently deposited from descending surface waters. In the richer sections of the vein a good deal of residual galena is present in this zone. It contains minute enclosures of primary argentite and also films and scales of what is evidently supergene argentite deposited in the cleavages of the galena.

This enriched zone is succeeded at a depth of from 30 to 35 feet by a *barren leached zone,* from 15 to 20 feet in vertical

thickness, in which the vein matter consists of a porous cellular or crumbly mass of quartz and limonite, having been completely leached of all its metallic minerals with the exception of part of the iron oxide.

The leached zone is in turn followed by (1) partly oxidized ore passing downward into unaltered ore, or (2) vein-stuff too poor in lead and silver to be worth working. Notwithstanding that the top of the leached zone at a depth of from 30 to 35 feet coincides roughly with the water table, the partly oxidized ore extends to 80 or even 90 feet below the surface. The ore exposed at this depth in some of the stopes consisted of residual masses of galena surrounded by secondary carbonates and oxides including malachite. Films of secondary chalcocite were also noted on partly oxidized pyrite in this zone. The siderite is just as susceptible to alteration as the sulphides of iron and copper. It undergoes oxidation, being converted into limonite. The unaltered mineral only appears in quantity in the unoxidized ore.

Summarizing, the following zonal arrangement can be made out in the oxidized portions of the poor and workable sections respectively of the Main Lode.

| Depth. | Poor Section. | | Workable Section. |
|---|---|---|---|
| 0–20–25 feet. | Gossan containing very little lead and silver. | | Residual galena accompanied by secondary carbonates, sulphates and oxides. |
| 20–25–30–35 feet. | Enriched zone. | | Enriched zone. |
| 30–35–45–53 feet. | Leached zone. | Water-level | |
| 45–53 | Unworkable vein stuff. | | Leached zone. |
| | | | Partly oxidized ore passing at a depth of from 80 to 90 feet into unaltered primary ore with siderite as the principal gangue mineral. |

## DISCUSSION OF THE PHENOMENA.

It appears from the foregoing that, apart from the presence of the leached zone, which, for the greater part, lies beneath the upper surface of the ground water, the vein presents the rather anomalous features that primary sulphides occur well above, and secondary carbonates and oxides well below, water-level.

It should be stated that the other veins of the area exhibit precisely the same phenomena as regards the occurrence of galena at the surface, and of oxidized ore far below water-level. There is, moreover, evidence in at least one of them, the Brakfontein Lode, of the existence of a leached zone at water-level. Very little work has ever been done on these veins, and the data relating to them are in consequence very meagre.

The occurrence above water-level and even at the surface of partly altered residual galena is quite a common feature of lead deposits. It is the natural consequence of the insolubility of lead carbonate and lead sulphate in oxygenated surface waters. The other phenomena, however, namely the leached zone and the pronounced oxidation below water-level, while not unique,[6] are unusual and call for special discussion. Before proceeding with this it will be useful to say something about the underground water circulation.

## THE UNDERGROUND WATER CIRCULATION.

The Main Lode, as already stated, is enclosed in medium-grained norite, which, toward the southeast, passes into coarse-grained pyroxenite. These rocks are much decomposed near the surface and are also much jointed and fissured, thus affording favorable conditions for the circulation of the ground-water. The water table stands normally at from 30 to 35 feet below the surface. There was a considerable influx of water into all the shafts and winzes at this level, sinking operations being thereby seriously impeded. The level of the water table, as a matter of fact, fluctuates with the season of the year and with the amount of the rainfall, rising in wet seasons and falling in dry seasons. It never, however, rises above 30 feet, the water evidently finding at about this depth a means of escape by lateral flow into the

[6] *Cf.* Knox, H. H., "An Instance of Secondary Impoverishment," *Trans. Inst. Min. and Met.*, vol. XVIII.; Stickney, A. W., "The Pyritic Copper Deposits of Kyshtim, Russia," ECON. GEOL., 1915, p. 606; Bell, J. Mackintosh, "The Occurrence of Silver Ores in South Lorrain, Ont.," *Trans. Inst. Min. and Met.*, Feb., 1922; Curtis, J. S., "Silver-Lead Deposits of Eureka, Nev.," U. S. G. S. Mon. 7, 1884.

bed of the marshy stream previously referred to, which intersects the vein at right angles. This necessarily implies a vigorous horizontal circulation of the ground-water at the level stated during the rainy season of the year. Below 80 feet the rocks surrounding the vein are practically unaltered and the joints and other openings are tight. In consequence little water occurs in the workings below this depth. The lower levels of the mine are quite dry.

### ORIGIN OF THE LEACHED ZONE.

An explanation of the leached zone and the pronounced oxidation below water-level may now be attempted. According to the writer's interpretation of the facts, both phenomena are to be attributed to a comparatively recent change of climate that had as one of its most important consequences a very marked rise of the ground-water level. In his memoir on the Pretoria Salt Pan [7] he showed that, so far as the area in which it is situated is concerned, there is clear proof that the present climatic period was preceded by one of great aridity. This view has been confirmed by the researches of Rogers [8] and Trevor,[9] and by more recent observations of the writer in the Waterberg district of the Transvaal. It is also supported by botanical evidence. It was during this arid period that the *pans* or *playas* of the High Veld, which are fairly common in the area under review,[10] came into being. How long ago the change from the arid to the present more humid conditions occurred there is no accurate means of ascertaining. Trevor would put it down at about 1,000 years, but there are good reasons for believing that a much longer period has elapsed.

As to the relation of this climatic change to the problems under discussion, it is well known that in arid and semi-arid regions

[7] "The Pretoria Salt Pan, a Soda Caldera," Mem. No. 20, Geol. Survey Union of S. Africa, Pretoria, 1922.

[8] "Post-Cretaceous Climates of South Africa," *S. A. Jl. of Sci.*, 1922, pp. 1–31.

[9] "Some Observations on the Influence of Past Climatic Conditions on the Human Occupation of the Transvaal." Paper read before the S. African Biological Society, in February, 1924.

[10] Several are shown near Argent Station on the accompanying map.

the ground-water either stands far below the surface, or there may be no continuous body of ground-water at all. In these circumstances oxidation and carbonation proceed to as great a depth as the permeability of an ore-body and the rocks surrounding it permit; the actual depth depending on the topographical relief and the nature of the lode matter and country rock. It is assumed that during the period of aridity the more alterable sulphides present in the ore and the siderite gangue underwent complete oxidation to a depth of from 80 to 90 feet, while the galena and argentite were partly oxidized. The coming of the humid period thus found the vein matter considerably altered to the depth stated and thereby rendered very porous.

As a result of the increase in rainfall the open spaces in the vein and in the rocks surrounding it were gradually filled with water, the level of which rose until it stood at from 30 to 35 feet below the surface, that is, very considerably above the bottom of the oxidized zone during the preceding dry period. The water table, as we have seen, is still subject to considerable oscillation. Before the setting in of the more humid conditions this oscillation was probably very much more pronounced. We may, therefore, visualize a zone that was, and to some extent still is, saturated with water at certain periods and dry at others; and in which there is during the rainy season a fairly vigorous lateral circulation toward the stream previously referred to. Conditions within it would clearly be eminently favorable to the solution of even very slightly soluble minerals and to the lateral dissipation of the dissolved matter. It is not surprising, therefore, to find that this particular part of the vein should have been completely leached of its lead, silver, and copper content.

The remarkable barren zone, which, according to the hypothesis advanced, coincides with the limits within which the ground-water level has fluctuated since the setting in of more humid conditions, and the pronounced oxidation below water-level are thus readily explained by the postulated increase in rainfall, and the underground drainage conditions.

THE ZONE OF ENRICHMENT ABOVE THE LEACHED ZONE.

There may now be considered the shallow enriched zone immediately above the leached zone. It is not uncommon in silver-lead veins to find that the bottom portion of the oxidized zone has been secondarily enriched by descending surface waters. Thus Hershey[11] states of the Caledonia Vein in the Cœur d'Alene district, Idaho, a region of heavy precipitation: "The metal salts have been largely leached from the vein near the surface and carried down to enrich the lower part of the oxidized zone." In the present instance the question arises: did the enrichment occur before or after the return to humidity?

It might, of course, be argued that the enriched zone is merely the upper part of a far more extensive zone of enrichment formed during the arid period. If that were so, however, it would be remarkable indeed that there is nowhere any marked enrichment below the leached zone.

Mr. Ritchie,[12] who particularly studied this question, writes:

> When payable ore occurs immediately below the leached out zone it is usually distinctly good, although I would not like to say that there is anywhere a noticeable enrichment. On the other hand, where unpayable ore occurs just below the leached zone there is certainly no local enrichment just on the upper limit.

Had the enriched oxidized ore formed during the arid period, the above-mentioned facts would necessarily imply that the enrichment had everywhere extended to below the irregular upper limit of the leached zone, and everywhere stopped above its irregular lower limit. The inherent improbability of that being so is so great that the assumption may be dismissed.

That the gossan capping the poorer sections of the vein should be practically barren of lead and silver, while there is a concentration of these metals in the zone immediately below, also suggests that the leaching and enrichment were due to an increase in rainfall.

[11] *Cf. The Mining and Scientific Press*, June 1, 8, 15, 1912.

[12] Personal communication to the writer.

It is concluded, therefore, that the zone of enrichment above the leached zone has come into being since the setting in of more humid conditions.

The absence of any marked silver enrichment beneath the leached zone is to be attributed partly to the dilution at and below water level, as a result of the increased underground circulation, of the descending surface solutions, and partly to the active oxidation during the preceding dry period which evidently left the accessible primary minerals thoroughly coated with sulphates, carbonates, and oxides, thereby rendering conditions very unfavorable to the precipitation of the metal.

## GENERAL.

There is nothing novel in the attempt made in the preceding pages to correlate the phenomena presented by the oxidized zone of a mineral vein with climatic changes. This has been done previously by H. H. Knox,[13] W. W. Atwood[14] and other geologists. Such changes have probably left their mark on the upper parts of many ore deposits and, while the evidence will probably rarely be as clear as in the case here discussed, their effects should be specially looked for in areas where there is reason to suspect their occurrence in recent geological times.

## ACKNOWLEDGMENTS.

The writer gratefully acknowledges his indebtedness to Mr. Jerome Ritchie, General Manager of the Transvaal Silver and Base Metals, Limited, for much of the information embodied in the present communication.

[13] "An Effect of Climatic Change on the Superficial Alteration of Ore Deposits," ECON. GEOL., 1922, pp. 655–661.

[14] "Physiographic Conditions at Bingham Canyon, Utah, when the Copper Ores of that District were Enriched," ECON GEOL., 1916, pp. 732–740.

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# THE RELATION OF HARDNESS TO THE SEQUENCE OF THE ORE MINERALS.

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THIS paper submits for consideration the following ideas, which are the result primarily of microscopical work on the ore minerals.

I. In most ores the harder minerals appear to have crystallized earlier than the softer ones.

II. The following explanations suggest themselves for this:

(*a*) A connection between hardness and insolubility.

(*b*) A general, fortuitous relation between hardness and rarity, of which the outstanding facts are that the iron minerals are in general hard and those of the rarer elements in general soft.

(*c*) Imperfections in our methods of estimating age relations in polished section.

## HARDNESS AND CRYSTALLIZATION.

In genetic sequences of ore minerals, as determined by examination of suites of ore specimens, there appears to be a pronounced tendency for the order of age to coincide nearly or quite exactly with the order of hardness of the minerals concerned. The commonest hard minerals are pyrite, arsenopyrite, magnetite, and specularite, and in the vast majority of cases they are reported as among the earliest to form. Sphalerite, pyrrhotite, chalcopyrite, and enargite, which are intermediate in hardness, are usually set down as intermediate in age also. Bornite, chalcocite, galena, and the soft sulphantimonites and sulpharsenites generally appear near the bottom of the paragenetic table.

Certain minerals, especially common ones such as pyrite, are sometimes reported as occurring in several generations, and mineralization is sometimes stated to have proceeded in several dis-

tinct stages. Distinct breaks of this sort are not ordinarily apparent under the microscope, but when they are mentioned in the literature, the minerals within each stage are usually found to be arranged in their order of hardness.

As for the gangue minerals, quartz and calcite may come in almost anywhere, but the hard silicates are ordinarily reported as earlier than the sulphides, and it is the softer silicates such as chlorite and sericite that are most closely related in age to the sulphides.

### HARDNESS AND INSOLUBILITY.

Hardness is presumably an expression of the cohesive force of the molecules of the mineral, which makes itself felt in resisting attempts to separate the molecules of the surface layer by mechanical means. Pöschl[1] has attempted to show that there is a relation between hardness and insolubility, hard minerals being in general more difficultly soluble than soft ones. He has shown also that other factors affecting hardness are the system in which the mineral crystallizes, its density deviation (the loss of volume shown by the compound as compared with a mechanical mixture of its elements), and a "personal factor" in the cohesive force of the different elements Without attempting to discuss all these, I would point out that if there is a connection between cohesive force and readiness to crystallize (insolubility), and also a connection between cohesive force and hardness, the connection between hardness and age may be easier to understand.

It may be pointed out here that the hard ore minerals are the most likely to be idiomorphic. Pyrite, arsenopyrite, magnetite, and specularite very commonly show an approximation to crystal outlines when seen in polished section; the softer minerals rarely do. Molybdenite is perhaps an exception, but its platy appearance is frequently an expression of cleavage rather than of crystal form.

[1] Pöschl, Victor, "Die Härte der festen Körper und ihre physikalisch-chemische Bedeutung," Steinkopf, Dresden, 1909.

### HARDNESS AND ABUNDANCE.

In addition to forming a scale of hardness, the genetic sequence frequently approximates an order of abundance of the elements concerned. The first minerals to form are silicates of the common elements, oxides of iron, and sulphides of iron (though of course arsenopyrite contains the less abundant arsenic as well). The zinc sulphide sphalerite and the copper-iron sulphide come next, very nearly contemporaneous. Lead (which is less abundant in the crust than either zinc or copper) comes later, and the sulphantimonites and sulpharsenites of copper, lead, and silver last.

There is an analogous tendency in the pegmatites for the first-formed minerals to be essentially those of the igneous rock with which they are associated and for the rarer minerals, when present, to be of later age. This may reflect the processes of differentiation taking place during the formation of the pegmatite, which would cause the final minerals to represent a more extreme stage of differentiation than the earlier ones. Some such process may take place during the formation of ore deposits. As far as the sequence of the ore minerals is concerned, however, it seems to hold only in a general way. The copper minerals in particular range for a fairly long distance over the scales of hardness and of age; but the later and softer minerals do contain more copper than the earlier and harder ones. The normal order for copper deposits is pyrite, chalcopyrite, bornite, (hypogene) chalcocite.

Iron is a very common element, and its commoner compounds are hard. It is questionable which of these two facts is the more important in causing the early formation of pyrite, arsenopyrite, magnetite, and specularite.

This correspondence between age of the mineral and abundance of the elements composing it falls down completely in the case of crystallization of igneous rocks, where the less common accessories are the first to form. It may be that this is due to the difference in conditions. In the one case all the constituents are on hand from the beginning, and the order of crystallization is

chiefly a matter of insolubility in the melt. In the other there may be a progressive change in the composition of the solutions, conditioned, as already suggested, by the progress of differentiation in the magma supplying them.

### IMPERFECTIONS OF METHODS.

Our criteria for determining age relations in polished section are still inadequate. In the early days of petrography it was accepted that where one mineral surrounds another the included mineral must necessarily be the older. More modern investigations have shown that this rule is by no means invariable, and we have no comprehensive rule to take its place. It is certain that a mineral which is, so far as can be seen, completely surrounded by another, may be either older or younger, and in many cases there is no way of deciding with any certainty which is the true or even the more probable explanation.

For example, the hard mineral specularite practically always shows euhedral faces where it occurs against a soft mineral like chalcopyrite. A polished section containing the two minerals will show detached plates of specularite surrounded (in the plane of the section) by chalcopyrite. Under the old rule this would be a clear case for the view that the specularite was the older. But since there is no question here of consolidation from a melt, and the minerals were certainly formed by replacement, we are faced by two alternatives: (1) that the specularite formed first by replacement of some pre-existing mineral and the chalcopyrite formed later by replacing the material around the specularite, or (2) that the specularite formed by replacement of the chalcopyrite. These two alternatives or something corresponding to them have to be faced in nearly every polished section of every ore. Frequently no definite convincing evidence can be found to show which is the correct one. If the specularite plates are broken and the interstices filled with chalcopyrite, or if they are corroded at the edges, it may be safe enough to conclude that they are the older, but if, as often happens, the plates are clean-cut and sharp, the question remains open.

The tendency, wherever a hard euhedral mineral comes in contact with a soft one, is for the observer to decide that the hard one is the older. Is our judgment unconsciously warped so that we are altogether too ready to make such a decision? I can confess frankly to a personal failing of this sort. When I see a rather ragged cube of pyrite surrounded by pyrrhotite or chalcopyrite I am likely to conclude immediately that the pyrite is the older. On the other hand an equally ragged cube of pyrite surrounded in the same way by altered wall-rock will lead to an equally quick conclusion that the pyrite is the younger. If the surrounding mineral be quartz or calcite the conclusion is likely to be neither immediate nor given with any assurance.

Frequently the crystals of a hard mineral such as pyrite are filled with inclusions of a softer one such as chalcopyrite. These inclusions are sometimes connected by visible channels with more chalcopyrite outside, in which case they are said to be younger than the pyrite. Sometimes the inclusions, though not visibly connected with the outside, are ragged and send tongues into the pyrite, in which case also they are said to be younger. At other times the inclusions are perfectly smooth blebs, with no sign of replacement either way, and we generally say rather doubtfully that they are younger, or ponder the possibility that they may be contemporaneous. If, however, we get the reverse case, rounded blebs of pyrite scattered through chalcopyrite, we never hesitate to say that the pyrite is the older.

Where two hard idiomorphic minerals come in contact, as for example where crystals of magnetite come against pyrite, there is almost always a good deal of doubt about the relations. Each tends to preserve its own form; neither yields entirely to the other. The most we can expect is that one will be noticeably cusped by the other. We may see rounded grains of magnetite protruding into a larger grain of pyrite, and we then say either that the magnetite is replacing pyrite or that the pyrite is "wrapping around" the magnetite. As magnetite can presumably be formed at higher temperatures than pyrite the latter explanation may be the more probable, but the evidence from the section itself is far from conclusive.

Where two soft minerals come in contact the variety of forms is greater. There are many cases where we can state the relative ages with a high degree of certainty, but there are many others where we can not. The smooth "mutual" boundaries of interlocking grains lead us to suppose as we study them in detail that replacement has gone now one way, now the other, and all we can do is to balance the two tendencies against each other and try to decide which is the stronger. And our conclusion is nearly always that the harder mineral is the older.

The foregoing paragraphs are written simply in the hope of providing food for thought and discussion. Our present criteria are confessedly inadequate, and if the reflecting microscope is to live up to its high promise more definite standards must be developed. We are living from hand to mouth, making our own rules to fit the special problems which each specimen offers, and the result is that even when the worker is convinced as to the age relations he is often unable to carry conviction to others.

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# EDITORIAL

## *SCIENTIFIC ORE FINDING.*

FROM the economic standpoint nothing can be more important than the recognition of the cause or causes that lead to the formation of an orebody in the spot where it is found, and those that controlled the distribution of values within that ore body, for on this intelligent ore-finding depends. From the scientific standpoint these problems possess an equal interest.

Yet surprisingly little definite, usable information has been obtained, or, at all events, is available, on this vital subject. Individual instances may no doubt be cited where these factors have been determined, and by applying this knowledge additional ore bodies have been discovered, but how exceptional these are! How indefinite and speculative or general on these points are the published statements regarding the majority of ore bodies!

Perhaps as convincing a test as any of the justness of the above assertion is a glance in a good modern text on ore deposits. The author, of course, recognizes the outstanding importance of this topic and is prepared to devote an appropriate amount of space to it. But how little there is to be said. After mentioning certain factors that may be operative, and stating that some appear to be more influential than others the subject is covered. Then turn to the descriptions of half a dozen of the most important ore bodies, and having read them ask yourself why they formed precisely where they did. If you can't answer do not blame the author. He did his best, but the information doesn't exist.

Ore bodies require much more careful study than they have yet received. Economic geology cannot be of the assistance to mining that it should be, a science of ore-finding cannot exist, until this close study has been devoted to ore-bodies. There is only one way by which this can be done adequately, and that is

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for geologists to be permanently on the spot, to follow all development and all ore-extraction. It cannot be done by a brief examination of the workings afterwards. A great deal of the evidence has been removed—what remains is covered with dirt, and it is pure chance if the geologist chips the critical spots. Having the walls washed and scrubbed down before examination is helpful and should be insisted upon in a geological examination of old workings. The cost is a mere trifle in comparison with the importance of the work and of the effect on capital of the decisions based upon it, or in comparison to the amounts spent on blind crosscutting, drifting and diamond-drilling.

If the walls are not washed, the geological information obtained depends on chance or on what a shift-boss, foreman or engineer can point out. If the latter, the geologist has to base his opinion on a fraction of the geological evidence possessed by the engineer and it will not be surprising if this opinion is not worth, to the engineer, what it costs.

But even if the walls have been cleaned, the geology cannot be seen as distinctly as when the breaks were fresh and work was proceeding, and much may be overlooked. If the workings are extensive there is also the question of time required for such a detailed examination. Much of the original evidence has been removed. This is particularly true of the stopes. There is usually very little to be seen in an old stope, but while stoping was in progress it was a veritable mine of information.

Then there is the time factor. Often a thing has to be seen frequently before it is recognized. An idea developes slowly. Long and profound thought is required before it takes shape and its significance is perceived.

Fortunately the practice of employing permanent geological staffs in mines is growing, though not nearly so rapidly as it should. When one sees the sums wasted on fruitless prospecting, and the number of mines that after years of work and miles of workings have no better knowledge of where to prospect than at the start, one wonders at their reluctance to take a chance on a permanent geologist. Perhaps they have already tried a ge-

ologist who was willing to sell an opinion based on a few days' examination, and have concluded either that geology is of no use to them in their business or else that such an opinion represents the sum total of the aid that geology can render.

But the time will come when those engaged in mining will recognize that ore finding is a strictly geological problem and that it pays to employ the man who knows or can find out. When the practice of employing geologists in mines has become universal, great progress will be made in solving the problems connected with the localization of ore-shoots and thus the problem of finding ore.

In this connection it would probably pay the mine, and it would certainly be in the interest of the science, to have the sampling under the supervision, or at least closely followed by, the geological staff, to ensure that the stopes are closely watched, and that the factors controlling the distribution of values may be discovered and available for use as early as possible.

The mine staff of geologists is unlikely to include specialists in all branches that may have a bearing on the problems. They should therefore call in specialists whenever such services might be of any value, as is now the general practice in connection with engineering problems. It is for geologists to see that their science is not hamstrung through lack of funds. In geological results as in everything else what one gets is pretty much what one pays for.

For the best results, the highest values, the necessary expenditure must be made. The results will soon justify the expenditure. Moreover it is human nature to value a thing according to what it cost.

Oil companies cheerfully provide the money for intelligent geological oil prospecting. There is no reason why mining companies should not do the same for intelligent geological ore prospecting, nor why if they do, it should not in a short time be attended by equally satisfactory results. But it is the geologists who will have to convince them of this.

R. W. Brock.

# DISCUSSION AND INFORMAL COMMUNICATIONS

## *THE SUDBURY ORE DEPOSITS.*

*Sir:* Messrs. Alfred Wandke and Robert Hoffman in their article entitled "A Study of the Sudbury Ore Deposits," appearing in the March, 1924, number of your journal, present some interesting data concerning these deposits. However, all the evidence they present does not, as I interpret it, support their hypothesis of the pneumatolitic origin for these deposits. There is much of the evidence which they present which does, in my opinion, strongly support the magmatic injection hypothesis, and even the metamorphism and metasomatic replacements they cite could equally well have resulted under the magmatic injection hypothesis, in which the magmatic ore material was injected in a colloidal gelatinous condition and was accompanied, from place to place, by varying amounts of gaseous mineralizers, which mineralizers would have been competent agents for the production of all of the rock alteration and disseminated mineralization accompanying the ore bodies.

I suggested this origin for the Sudbury copper-nickel sulphide deposits in a discussion[1] of the article on the geology of the Creighton mine, by the staff of the International Nickel Company,[2] in which they supported the hypothesis of the ores having been intruded in a molten condition.

When an igneous intrusive body, or a dike of igneous rock, contains within its mass fragments of rock of an entirely differ-

[1] *Trans. Can. Inst. Min. and Met.*, vol. XXIII., 1920, pp. 107–111.

[2] "The Mining and Smelting Operations of the International Nickel Company of Canada, Limited," *Trans. Can. Inst. Min. and Met.*, vol. XXIII., 1920, pp. 19–107.

ent character from that of the intrusive itself, it is generally conceded that the inclusions were derived from the invaded rocks and that they were floated in the pasty, sticky mass of the igneous material, undergoing little or great alteration, depending upon whether the composition of the intrusive material was neutral, or active chemically, toward the included pieces of the invaded rocks.

Rock inclusions in fissure veins were, however, if at all considered, given an entirely different interpretation, and they were supposed to have been supported in some way, as remarked by J. E. Spurr, in a recent article,[3] by something behind the included rock fragment and out of sight of the observer. The common acceptance of such a supposition for so long a time is most amazing when often an individual inclusion of probably but several inches in diameter was as many feet either way from the walls of the vein, or other inclusions. While in the idea of the crystal growth of quartz veins it seemingly is forgotten that a force sufficient to force apart the walls of a fissure in solid rock would effectually prevent the separation of any material from the walls. It remained for J. E. Spurr to forcefully bring to the attention of geologists that there was a more probable, logical, and reasonable way [4]—that of injection of the vein material in a pasty, gelatinous condition, thereby giving buoyancy to any fragments that may have been detached from the walls when the fissure was being opened by the advancing magmatic material.

What obtains for fissure quartz veins, also with equal force, can be applied to certain fissures filled with sulphides, such as the Sudbury deposits.

My studies of ore deposits of the "vein-dike" or intrusive type have brought me to the conclusion that the conditions sur-

[3] "The Origin of Metallic Concentrations by Magmation," ECON. GEOL., vol. XVIII., No. 7, Oct.–Nov., 1923, pp. 633–634.

[4] The Ore Magmas. "The Filling of Fissure Veins," *E. & M. J.–P.*, Aug. 25, 1923, pp. 329–330. "The Gold Ores of Porcupine," *E. & M. J.–P.*, Oct. 13, 1923, pp. 633–638. "The Pre-Cambrian Veins of Kirkland Lake, Ontario," *E. & M. J.–P.*, Oct., 20, 1923, pp. 671–672. "The Nature of the Silver Veins at Cobalt," *E. & M. J.–P.*, Oct. 27, 1923, pp. 709–712.

rounding the intrusion of igneous rock masses are practically duplicated in the formation of fissure veins and the magmatic sulphide deposits. Fissuring and shattering, injection of magmatic material under pressure from below into the openings, the more or less alteration of the included fragments and the margins of the intruded rock by the accompanying mineralizers, are all notable features of both types of occurrences.

The authors present certain evidence in connection with the enclosing rocks and the ore bodies which would seem, in my opinion, to strengthen the hypothesis of the intrusive nature of these ore deposits.

To deal with the enclosing rocks first; they say in regard to the Murray mine:[5]

> The granitized greenstone is also well epidotized, in this respect being strikingly similar to the occurrence at Levack.

Of the rocks at the Levack mine:[6]

> In a broad way granite intruded a basic rock called greenstone, and fragments of the latter rock in various stages of alteration are preserved in the granite. Exposures in the open cut show excellent examples of granitized brecciated greenstone.

Of the rocks at the Worthington mine:[7]

> Within the quartz diorite are numerous rounded fragments of actinolitic rock.

No doubt if this phase of the enclosing rocks of the other mines of the district had been dwelt upon, similar conditions would have been recorded for them. However, the quotation above, regarding the rocks at the Levack mine, gives a perfect picture of granite intruding shattered greenstone with the more or less alteration of the inclusions of greenstone fragments by the mineralizers which accompanied the granitic magma.

The analogy between the above quoted descriptions and those of the ore deposits is most marked. They say for the Creighton mine:[8]

[5] ECON. GEOL., vol. XIX., No. 2, March, 1924, p. 188.
[6] *Op. cit.*, pp. 189–190.
[7] *Op. cit.*, p. 195.
[8] *Op. cit.*, p. 184.

In the ore bodies angular blocks of granite abound along the foot side. Each of these blocks shows a black rim of hornblende and biotite which separates the unaltered granite from the encroaching sulphides.

For the Levack mine:[9]

It differs from the Creighton deposit in . . . that the ore carries much more rock in proportion to sulphides, necessitating about 33 per cent. of hand sorting; that the minerals associated indicate a lower temperature of the mineralizing solutions.

For Crean Hill:[10]

Our specimens from this locality are few in number and represent merely ore-bearing rock. . . . Included fragments, probably shale, show contact metamorphism.

For the Frood mine:[11]

The gabbro appears to have been well brecciated before the ore solutions entered for the ore cements fragments of the gabbro. In the diorite, on the other hand, the ore occurs as blebs rarely over a half inch in section. These blebs at once recall the grains of sulphides in certain phases of the main nickel eruptive, and in the hand specimens the ore suggests that sulphides and silicates were formed contemporaneously. There are however abundant specimens which show that the sulphides cut the diorite.

They stress the fact that the rocks were shattered before the ore-forming processes became operative, and in their enumeration of facts of occurrence their study of the deposits has brought out, they say:[12]

In all cases, whether dealing with a marginal or an offset deposit or even a narrow vein in the norite, there is evidence of shattering that opened the way for the ore solutions, . . . .

Also:[13]

Brecciation and rock replacement are two striking features of the Sudbury ore deposits, . . . .

It is thus seen that all the phenomena of shattering, injection, and the alteration of inclusions and marginal areas by the gran-

[9] *Op. cit.*, p. 189.
[10] *Op. cit.*, p. 192.
[11] *Op. cit.*, p. 194.
[12] *Op. cit.*, p. 201.
[13] *Op. cit.*, p. 202.

ite are duplicated, though of course on a smaller scale and probably with less intensity, by the processes accountable for the ore deposits. Is such evidence as this of a close relationship of origin to be counted for naught?

The intrusion, long after the solidification of the norite, of the copper-nickel sulphides in a colloidal gelatinous condition and accompanied by gaseous mineralizers, instead of in a molten condition, would meet all of the facts of occurrence I have seen set forth by the many investigators who have studied these deposits.

That an occasional mind is devoting thought to heretofore little considered processes for the explanation of the origin of ore deposits is again evidenced by the editorial entitled "Science and Dogma," by Professor F. L. Ransome, in the March, 1924, number of this journal, in which he calls attention to the indefinite state of our knowledge of how ores were deposited, and closes by asking:

> Are there not possibilities in colloidal chemistry, in diffusion, and perhaps along other lines, that have not yet been adequately considered as factors in the genesis of ores?

JACOB W. YOUNG.

MONTEBELLO, CALIFORNIA.

## *CONTACT EFFECTS OF GABBRO AND GRANITE ON ORE DEPOSITION.*

*Sir:* In a recent paper[1] the writer described in detail the marked difference in the contact effects of acid and basic rocks as shown by granite and gabbro intrusions into the Ely greenstone of northeastern Minnesota. It is believed that some of the points brought out are of importance in connection with the association of ore deposits with acid and basic rocks.

It is well known that metallic deposits of epigenetic origin are more abundantly associated with the intermediate and acid rocks than with basic rocks. The evidence presented here favors the theory, which has been suggested by various investigators, that

[1] Schwartz, G. M., "The Contrast in the Effects of Granite and Gabbro Intrusions on the Ely Greenstone," *Jour. Geol.*, vol. 32, pp. 89–138, 1924.

basic magmas are so essentially deficient in water and other so-called mineralizers that there is a lack of an adequate means for transporting the metals to places suitable for deposition. One of the intrusives studied is the Duluth gabbro, a mass 150 miles long and as much as 30 miles wide. The gabbro represents the major part of the intrusive, but a red rock differentiate is found at the top of the lopolith. Recent studies by the writer have shown that chalcopyrite is widely disseminated through the gabbro. Analyses also show the presence of copper. Notwithstanding this fact there are no known chalcopyrite deposits, even small ones, in or near the gabbro, although this lack of deposits was not due to an absence of copper in the magma. There is perhaps enough to form several mines were it segregated into a few places. In the case of the particular granites studied, deposits are also lacking, but of course this does not affect the generalization regarding the abundance of deposits around granitic intrusions.

The contact metamorphism studied was mainly the effect of four granite masses and the Duluth gabbro on the Ely greenstone, a more or less altered and metamorphosed body of Archean basalt. The normal phase of the greenstone consists principally of plagioclase, chlorite, hornblende, epidote, calcite and magnetite, with lesser amounts of sericite, leucoxene, quartz, actinolite, kaolin, limonite, pyrite, augite, and other minerals, which appear only rarely. The primary augite is usually entirely altered to uralite and chlorite and the feldspar is usually a mass of sericite, paragonite, calcite, and other secondary products. Other secondary hydrous minerals, such as leucoxene, are common if not abundant.

Wherever the granites intrude the greenstone, a hornblende rock is found, normally a schist. Hornblende, plagioclase, magnetite, epidote, zoisite, quartz, titanite, chlorite, actinolite, with lesser amounts of sericite, kaolin, leucoxene, biotite, pyrite, etc., compose this rock. The feldspar is clouded with alteration products, especially sericite and kaolin. A study of the rocks from a distance up to the contact shows a progressive increase

of hornblende, but the feldspar even in inclusions of greenstone in the granite, is filled with sericite, and other minerals, such as kaolin, chlorite, leucoxene, and carbonates remain as accessory constituents. It should be noted that many of these minerals are hydrous.

The rock at the gabbro contact is in marked contrast with that at the granite contact. The principal minerals in order of abundance are plagioclase, augite, magnetite, olivine, biotite, diallage and hypersthene, with lesser amounts of several others. Hornblende is an intermediate mineral between chlorite and augite, as is shown in the paper cited above, but is almost entirely absent at the contact, as are hydrous minerals such as sericite, paragonite, kaolin, leucoxene, and limonite, which are found in the normal and granite contact phases of the greenstone. The feldspar at the gabbro contact has recrystallized to notably fresh grains free from the alteration products so conspicuous at the granite contact.

Effects similar to those described above have been noted for several other types of rocks, but these need not be described here. The greenstone is a typical case.

Hornblende, the characteristic mineral of the granite contact rocks has, not only water, but also fluorine as shown by Penfield and Stanley.[2] The presence of other hydrous minerals in the granite contact rock has been especially noted above. In contrast, the rock at the gabbro contact is almost entirely lacking in the above minerals, but contains much augite which has very little if any water. From the evidence noted above, it is clear that whereas the granite magma favored the preservation and formation of hydrous minerals, such as sericite, the gabbro magma in place of contributing water completely dehydrated rocks with which it came in contact. This indicates clearly the presence of water and probably also other mineralizers in the granite magma that were absent in the gabbro magma.

If it be true that basic magmas are relatively dry and free from so called mineralizers, especially at the contacts, then it is

[2] Penfield, S. L., and Stanley, F. C., "On the Chemical Composition of Amphibole," *Am. Jour. Sci.*, vol. 23, 1907, pp. 23–51.

not at all surprising that epigenetic ore deposits are rare as a direct result of their intrusion. There is a lack of an agency to carry the metals to the borders or otherwise segregate them into veins, although there may be a considerable metallic content, as noted above for the Duluth gabbro. Granitic magmas are, on the contrary, apparently well supplied with water and other mineralizers, and contribute them to the intruded rocks, as shown by four distinct granite intrusives in Minnesota. That ore deposits are abundant in connection with acid intrusives in general is well known although the particular granites studied happen to lack such deposits.

G. M. SCHWARTZ.

UNIVERSITY OF MINNESOTA.

## *THE EDUCATION OF THE GEOLOGIST.*

*Sir:* I have before me Professor Lindgren's paper on "The Education of the Geologist," printed in the June–July number of ECONOMIC GEOLOGY last year (Vol. XVIII.). I am heartily in accord with practically everything that Professor Lindgren says, especially regarding the necessity for including, among the requirements for an undergraduate degree in geology, a thorough course in topographic surveying and instrumental mapping, training in descriptive geometry and calculus, a reading knowledge of at least one modern foreign language and so on. Instead of "some knowledge of English," I should say that as thorough a training as possible in our own language ought to be demanded. There is no branch of learning, technical or otherwise, that can suffer from the use of correct English.

However, I am not writing to criticize, but to expand a little upon the subject from another angle. If I may be pardoned for being somewhat personal, I want to state a few of the impressions which have come to me while in charge of the geological department of an oil company.

Professor Lindgren refers to the effect of the recent great demand for petroleum geologists, saying that "too often they are

turned out simply provided with the minimum of knowledge necessary for an 'outcrop hound' or for the chasing of anticlinal structures, but quite useless for the advancement of geology" (p. 405).

Unfortunately there is a great deal of truth in this remark. There has been a misconception very common among undergraduate students, and not unknown among educators and business executives, that petroleum geology is a simple, easy, restricted branch of the science in which little more is really necessary than a special knowledge of some stratigraphic and structural conditions, almost to the entire exclusion of the study of igneous and metamorphic rocks.

I wish emphatically to protest against this false idea. We are finding more and more that the anticline is but one of many types of structure which may control the accumulation of oil. Moreover, the simple charting of well-exposed anticlines is almost a thing of the past, for most of those which are readily apparent have been discovered. Surface mapping is now much more difficult than it was five years ago, and proper recommendations require more experience and judgment.

To show how comprehensive the technical education of the petroleum geologist must be, I may say that during the last two years the field work of our department has called for the recognition and investigation of such igneous rocks as granite, diorite, andesite, felsite, and basalt; of volcanic breccias and agglomerates; of laccoliths, dikes, sills, volcanic necks, plugs, and flows; of contact metamorphic phenomena; of metamorphic rocks including quartzite, schists, gneisses, etc.; of all sorts of present physiographic features; of the conditions of unconformity and overlap, which are related to ancient physiographies; of types and relations of faults; and of veins and vein deposition. The scope of these studies is not at all exceptional for the geological department of an oil company.

Petroleum geology is not merely field work. It includes the correlation of well logs and their interpretation for constructing maps of subsurface structures. The microscopic examination of

rock cuttings and minute fossils is gradually being introduced. Much is being done toward the elucidation of structural conditions by comparing the chemical analyses of underground waters.

Petroleum geology is a complex science. It is young and it has a long life in the future. There is an immense amount in it still to be learned. It is preëminently a science for those who have a fondness for research, for its problems are manifold and various. It makes a direct appeal to investigators. It is constantly striving, through the correlation of facts, to seek and develop new theories which will be of use from a practical standpoint. Herein lies its greatest attractiveness.

Now, what does all this signify? It means that the college undergraduate should be made to understand that petroleum geology is a field for men of ability and perseverance, for men who are well trained in all the fundamentals and who are eager to work and continue studying. It means that those who are responsible for the curricula of colleges should appreciate the breadth of the field of petroleum geology, and should adjust their programs to graduate the kind of men we need for this branch of science. It means that the university which turns out the best all-round men for petroleum geology is not necessarily the university surrounded by oil fields, but is the university which best realizes, through its teachers and its courses, the needs of the science.

Petroleum geology is intimately and forever bound up with the second greatest business of our country, a business which is of the utmost importance in the future life, power, and economies of the nation. Surely, therefore, should not its status be clearly understood by our educators?

FREDERIC H. LAHEE.

SUN OIL CO.,
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# REVIEWS

**Långbansmineralen från geologisk synpunkt.** (The Långban minerals from a geological point of view.) By NILS H. MAGNUSSON. Geol. Fören i. Stockholm Förhandl., 1924, pp. 284–300.

The Långban mines, near Filipstad in western central Sweden, exhibit a greater number of mineral species than any other single deposit. The geological environment of this highly peculiar association has not previously been satisfactorily studied, although great credit is due the late manager H. V. Tilberg, who carefully recorded all geological facts observed in mining the deposit. Mr. Magnusson's paper is a preliminary report on work carried out for the Geological Survey of Sweden. The Långban deposit contains iron ores and manganese ores. Although closely associated, they are well separated from each other, there being rarely more than one or two per cent. manganese in the iron ore and the same amount of iron in the manganese ore. The country rock is dolomite. Both kinds of ore are clearly replacement deposits. The iron occurs as specular hematite, and magnetite. Brick red jasperoid is associated with the hematite, while the magnetite is accompanied by skarn silicates, as diopside, amphibole, garnet. The magnetite ore and skarn surround the bodies of hematite and jasperoid. The relations clearly indicate that the former association is developed by a recrystallization and alteration of the hematite-jasperoid combination. An early stage in this change is marked by the appearance of "porphyroblasts" of magnetite in the hematite.

The manganese ore is braunite ($3\ Mn_2O_3\ MnSiO_3$) and hausmannite ($Mn_3O_4$). The latter is accompanied by a skarn of manganese pyroxenes, amphiboles, garnet and olivines. The relations between braunite and hausmannite (with skarn) form an exact counterpart to those of hematite and magnetite. The development of hausmannite porphyroblasts is well illustrated. Reflected polarized light is used with excellent results to bring out the difference between the regularly twinned hausmannite grains and the braunite. Basing his verdict on the relations as seen both in the mine and under the microscope, and also on the analogies to the hematite-magnetite combination, the author takes exception to the views recently put forth in this journal by Mr. Geo. A. Thiel, who regards the association as a replacement of hausmannite by braunite. Mr. Magnusson shows that the braunite inclusions in the hausmannite occur

like the inclusions generally found in porphyroblasts, as of garnet in a schist.

The parageneses now shown to belong to two distinct periods are explained as follows. At first iron was deposited as oxide, manganese as oxide and partly carbonate, some of which is also still left. With the iron came the silica of the jasperoid. The geological facts admit of no other explanation than that the iron and manganese ores belong to the same period of mineralization. The salient problem, then, is the explanation of their deposition as separate ore bodies. Chemical facts probably explaining this relation are quoted from works of J. H. L. Vogt, Hj. Sjögren, W. H. Emmons and E. C. Sullivan, on the deposition of sedimentary iron and manganese ores. The presence of abundant oxygen appears to account for the separate deposition of iron and manganese, the occurrence of manganese oxide and carbonate but no $FeCO_3$, the presence of lead as silicates instead of sulphide, and of arsenic as acid radicles, etc. Later, a rise of temperature has caused the change of hematite to magnetite, of braunite to hausmannite, and the accompanying skarns. It is not yet clear whether this second period followed immediately upon the first, or was much later.

Lead, arsenic, and antimony occur constantly in all the ores of Långban. Of the lead silicates, kentrolite and melanotekite occur with the primary ores, ganomalite and hyalotekite with the skarn ores. Similarly, the primary arseniate karyinite is replaced by berzeliite, an alteration found long ago by A. Sjögren and W. Lindgren. Therefore, also the lead and arsenic minerals can be divided into those of primary deposition, and those of the second, or skarn, period. The same holds true of the antimony. To the second period are referred also periclase, MgO, and manganosite, MnO. Largely corroborating views previously presented by Hj. Sjögren, the author concludes that these oxides have been formed by heat metamorphism, but probably of the carbonates and not, as suggested by Sjögren, of the hydrates. The manganosite further alters to hausmannite, which fact explains the occurrence of disseminated hausmannite, an ore type distinct from that originating by the metamorphism of braunite ore. The occurrence of some ZnO in periclase is of particular interest, as pointing to a similar origin—metamorphism of carbonate—in the case of the zincite of the New Jersey deposits, which in so many respects duplicate the Långban parageneses.

Later than the skarn minerals are the "fissure minerals," representing a third period. In this group is found a great part of the famous Långban minerals, as arsenites, native lead, pyrochroite, thaumasite, tillasite, margarosanite.

The deposition of the fissure minerals is regarded as an end phase of

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the skarn period. An open problem relates to the possible introduction of new substances during the second or third periods. Mr. Magnusson holds that most of the elements appearing at Långban are contained already in minerals of the first period. For some of them, however, this is not yet proved. The paper ends with a scheme illustrating the distribution among the three periods of minerals, the relations of which are definitely known. This list shows 8 minerals in the original replacement deposition, 27 in the second, or skarn, period, and 35 in the third period, that of the fissure minerals.

It seems to the reviewer that this attempt to "regard the Långban minerals from a geological point of view" forms a very important step towards a fuller understanding of this unique deposit. Continued work along the lines now traced promises to result not only in a definite answer to the long-asked question how the Långban ores have been formed, but also in a reliable framework in which to place the results of studies of mineralogical details. The very important work carried on by G. Frank, G. Aminoff, and others, will in this way obtain increased value.

As the report is a preliminary one, and the author himself points out some of the most important gaps, where further study is needed, there is little room for positive criticisms. It may only be added that the original deposition, with colloidal silica replacing dolomite, appears to have been a very "shallow" process.

PER GEIJER.

DJURSHOLM,
SWEDEN.

**The Geology and Ore Deposits of the Tavoy District.** By J. COGGIN BROWN and A. M. HERON. Memoirs of the Geological Survey of India, vol. XLIV., part 2, 1923. 354 pages.

The Tavoy district affords one of the best examples in the literature of close areal and genetic association of tungsten and tin veins with pegmatites and the close relationship of both with igneous intrusions. The district lies in Burma near the southward-flowing Tavoy River, which empties into the Bay of Bengal. Siam lies immediately to the east. Except for the Tavoy Valley the region is rocky and mountainous and is about 150 miles long by 60 miles in maximum width.

Mining in the district commenced only in 1910, but the district rapidly progressed in importance until in 1914 it produced 2,300 tons of tungsten concentrates out of a world's total of 8,000 tons, and in 1917 it produced 4,480 tons out of a world's total of about 28,000.

The predominant rocks of the district are highly folded but little metamorphosed sediments termed the Mergui series, which are intruded

by granite as large and small bosses. The Mergui series consists of indurated crushed shales, with subordinate conglomerate and limestone. The sediments are so uniform and so mantled by forests and soil that structure cannot be worked out in detail, but the general strike is NNW., parallel to the general trend of the mountain ranges and to the long axis of the granite intrusions. This is also the usual strike of the tungsten and tin veins. The sedimentary beds are clearly much folded, for dips range from 60 degrees to verticality. Weathering is at a maximum in this tropical region, and fresh rock exposures are found only in the streams and in a few of the mines. No fossils have been discovered in the Mergui series. In age it is probably pre-Cambrian, but possibly early Paleozoic. Next the granite and associated pegmatite the series has been contact-metamorphosed in places to produce phyllites and mica schists, locally with the development of some garnet.

All of the granite intrusions appear to be of the same age except for certain tourmaline pegmatites. The granite carries both orthoclase and acid plagioclase, and biotite is the principal dark mineral. The texture is commonly coarse and porphyritic near the centers of the intrusions, becoming finer near the borders. No chilled contacts occur. Minor intrusions include pegmatites and quartz veins and feldspar porphyry which are of approximately the same age as the granite and probably offshoots therefrom. There are also present basic dikes and tourmaline pegmatites which appear to be younger than the granite. No economic minerals are found in the tourmaline pegmatites, and they appear to have no relation to the metalliferous veins in the Tavoy district. In neighboring districts the tourmaline pegmatites are however obviously related to the tin and the tungsten mineralization. Inclusions of Mergui sediments are common in the granite and show surprisingly little alteration.

Wolframite and cassiterite, the principal economic minerals of the district, occur (1) as segregations in muscovite granite, (2) in true pegmatite veins, (3) in quartz veins carrying mica, fluorite, and a variety of sulphides, (4) in greisens with mica and pyrite. In addition, wolframite and cassiterite occur in residual and talus deposits, and cassiterite in placer deposits. Some scheelite is found in the district, but is of no economic importance.

The segregation occurrences in granite, while of theoretical interest, are of no economic importance. The occurrences in pegmatites are economically important at several mines. At the Pagaye mine, the wolframite is intercrystallized in the pegmatite with microcline feldspar, mica, green fluorite, scheelite and cassiterite, together with pyrite and chalcopyrite. The manner of intergrowth leaves no room for doubt as to the wolframite and cassiterite being original pegmatite components.

Fissure veins constitute, however, the source of most of the wolframite and cassiterite. In addition to these ore minerals, the veins contain:

*Common Sulphides:* Pyrite, Chalcopyrite, Molybdenite.

*Rare Sulphides:* Galena, Sphalerite, Pyrite, Arsenopyrite, Stibnite, Bismuthite.

*Elements:* Bismuth.

*Miscellaneous:* Mica, Topaz, Fluorite, Siderite, Calcite.

The fissure veins are all in the granite or close to its border. Mica, usually muscovite, is an almost invariable vein associate, green chlorite is also found, and may be lithium-bearing. Cassiterite is in relatively greater proportions in veins in the granite than in those in the sediments. Noteworthy features of the veins are their frequent occurrence in parallel groups or in series of overlapping lenses. The individual lenses are often irregular, thinning and thickening, or splitting and reuniting. They possess sharp and well defined walls. Alteration of granite walls to greisen next the veins is practically universal.

A large portion of the Tavoy wolframite is won by hydraulic methods from residual and detrital deposits, but no tungsten placers, in the sense of stream-borne and water-sorted alluvium occur, for, because of its perfect cleavage, the wolframite becomes finely comminuted before it can be incorporated in stream gravels.

Observations show that under these tropical conditions wolframite is readily leached from the weathered outcrop. Sometimes nothing is left but the empty spaces once occupied with the crystals; at other times these are filled with oxides of iron and manganese or with the bloom of the yellow hydrous oxide of tungsten,—tungstite. Owing to its friability the tungstite is easily carried away by tropical rains and is of no economic importance. The authors believe that there is also extensive oxidation and solution of the sulphides of molybdenum and bismuth. No evidence was found of the redeposition of tungsten in sufficient amounts to produce any noteworthy secondary enrichment, comparable, for example, with that common in certain copper and silver deposits. Some apparently secondary ferric tungstate, or hydrated tungstic oxide, was noted, but this cannot be economically recovered.

EDSON S. BASTIN.

# SOCIETY OF ECONOMIC GEOLOGISTS

The Scholarship financed by royalties from POLITICAL AND COMMERCIAL GEOLOGY has been awarded for the collegiate year 1924–1925 to Mr. A. H. Redfield of Washington, D. C. Mr. Redfield will continue his studies of foreign oil deposits at the George Washington University and in the library of the U. S. Geological Survey.

The Council desires to call attention of the members of the Society to the meeting of the International Geological Congress to be held in Spain in the spring of 1926. It is the hope of the Council that a large number of members of the Society will attend the Congress. To economic geologists the excursions should be of particular interest. There will probably be an opportunity for the members of the Society to meet informally and discuss Society affairs and later to give the Council the benefit of opinions of members who in the past have rarely been able to attend meetings.

The referendum regarding the form of publication of the separates of the Society shows that a majority of the members desire to continue the present form of publication. In consequence, as heretofore, the publications of the Society will be sent out as issued rather than be held until material for a bound volume accumulates. Volume I. of the publications of the Society of Economic Geologists includes publications Nos. 1 to 29 inclusive, that is, all papers published from 1921 to 1923 inclusive.

# SCIENTIFIC NOTES AND NEWS

W. C. Mendenhall, chief geologist of the U. S. Geological Survey, recently returned to Washington from a field trip to Michigan, the Black Hills, Denver, Syracuse, Tulsa, and Texas.

Kenneth C. Heald has commenced his work at New Haven as Associate Professor of Geology at Yale University.

D. H. McLaughlin has returned to Peru after four months in the United States to take up his work as chief geologist of the Cerro de Pasco Copper Corporation.

J. S. Flett, Director of the Geological Survey of Great Britain, and several of his associates visited the Survey and other scientific institutions in Washington recently.

Kirk Bryan, of the U. S. Geological Survey, is making a geologic investigation of sites for tunnels and reservoirs for the Owyhee project of the Bureau of Reclamation, with headquarters at Boise, Idaho.

H. Dewitt Smith, formerly with the United Verde Copper Company at Jerome, Arizona, has accepted a position in the industrial department of the New York Trust Company.

P. B. Dowling has returned to Canada from England, where he represented the Department of Mines at the British Empire Exhibition.

John Reid, previously with the O'Brien mine at Cobalt, has accepted appointment as consulting engineer to the Bingo Gold Mines, Ltd., at Herb Lake, Manitoba.

R. T. Hill, of the U. S. Geological Survey, who spent several months in Washington working on his trans-Pecos report, has returned to California.

George E. Farish is in Italy for several months on business, and will visit the mines of Transylvania before his return to this country.

A. A. Pegau, Fellow in Geology, Cornell University, has been appointed Assistant Professor of Geology at the University of Virginia.

R. A. Smith, State Geologist of the Michigan Geological Survey, has been investigating the iron-bearing district of northern Michigan.

W. W. Rubey, C. E. Dobbin, and T. W. Stanton, of the U. S. Geological Survey, have completed a reconnaissance trip over parts of the Powder River Basin, in northeastern Wyoming.

E. C. Saint-Smith has returned to the service of the Queensland Geological Survey, from which he resigned in February to take up the

position of mines superintendent of the Mount Isa Mines, Ltd., of Cloncurry.

The parties under Philip S. Smith, which have been making geologic and topographic surveys in Naval Petroleum Reserve No. 4 on the Arctic coast of Alaska, have returned to Washington.

J. L. Stuckey, instructor in geology, Cornell University, has been appointed Assistant State Geologist of North Carolina.

F. B. Laney, head of the department of geology of the University of Idaho, is preparing a Professional Paper dealing with the genesis of the ore deposits of the Seven Devils area in Washington and Adams counties for the U. S. Geological Survey.

Thomas M. Bains, Jr., of the University of Illinois, has accepted a position at the Colorado School of Mines as associate professor of mining.

Olaf P. Jenkins has made a geological investigation of the lead deposits of Washington State for the Division of Geology, Department of Conservation and Development.

Y. M. Hsu has been studying the marble quarries near Chingkiang for the Kiangsu Provincial Geological Survey, and C. C. Ling is about to take up a study of the I-hsing pottery industry.

D. R. Semmes, Assistant Chief Geologist of the Joint Geological Department of the Aguila and Corona Companies, Tampico, Mexico, has resigned his position and is returning to New York where he expects to establish himself in a consulting capacity.

Dabney E. Petty, of San Antonio, Texas, has recently become associate geologist in the Bureau of Economic Geology and Technology of the University of Texas, succeeding T. L. Bailey, who will be absent on leave in the University of California.

Edmund Jussen, mining engineer and geologist, has established headquarters in San Francisco with the Diamond Drilling Company.

Max W. Ball, a member of the Board of Trustees of the Colorado School of Mines, has been active in establishing a professorship in oil shale mining and refining.

Charles H. Gould, director of the Oklahoma Geological Survey, is preparing several publications on the mineral resources of Oklahoma. It has been estimated that the average value of Oklahoma's mineral production for the last six years has been $354,000,000, of which petroleum supplied 87 per cent.

A. H. Brooks, R. H. Sargent, and J. S. Brown have returned to Washington from Alaska.

John K. Knox, formerly geologist for the Whitehall Corporation in India, and more recently in consulting work at Houston, has opened offices as consulting geologist in the Patterson Building in Denver, Colorado.

C. Lorimer Colburn, formerly with the U. S. Bureau of Mines, has resigned to engage again in private practice as consulting mining engineer, with headquarters at Denver.

As a part of a comprehensive plan to improve the industries of Cincinnati, the Commercial Club of Cincinnati is financing a scientific study of the raw materials in Ohio and other states which may be commercially tributary. The work is to be done in the University of Cincinnati, largely by the staff of the Department of Geology and Geography. After collecting available data, supplementary field work will be necessary. Provision is also made for technological work. These studies will continue for several years and will cost at least fifty thousand dollars. In connection with the proposed survey, Charles H. Behre, Jr., formerly in the Department of Geology of Lehigh University, has been appointed Assistant Professor in the University of Cincinnati, with the duties of teaching in the Department of Geology and serving as executive secretary of the survey.